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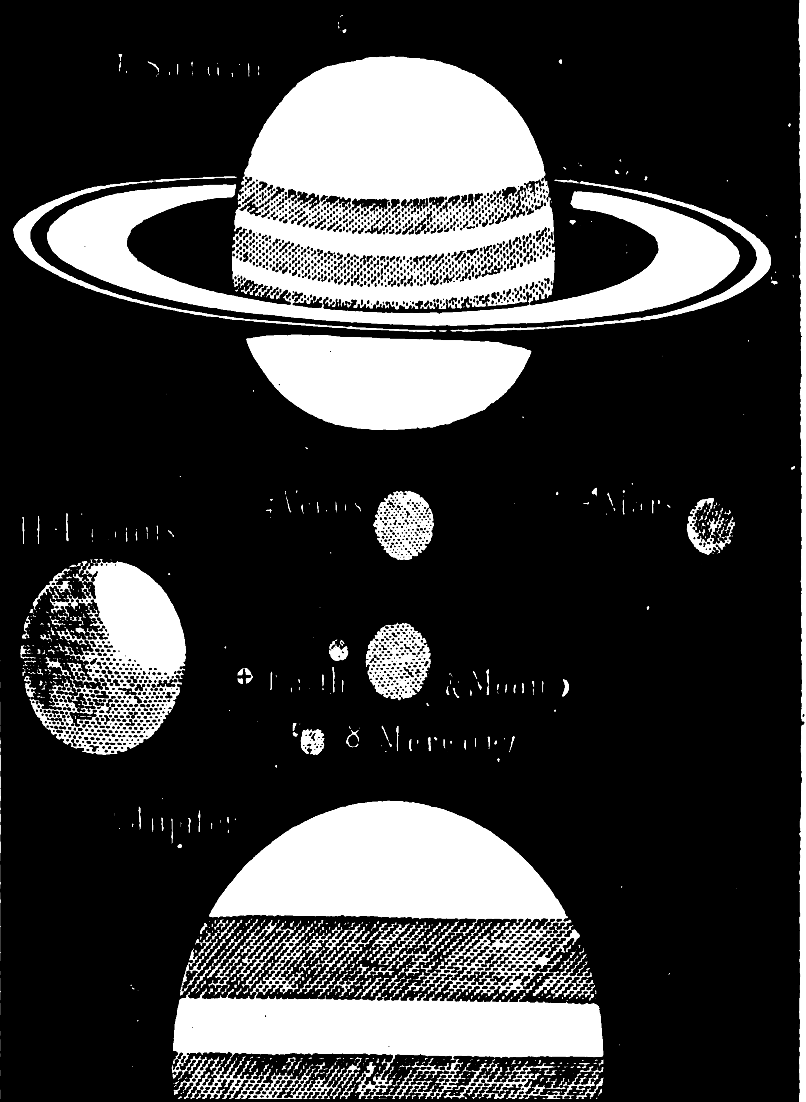

Elements of Astronomy

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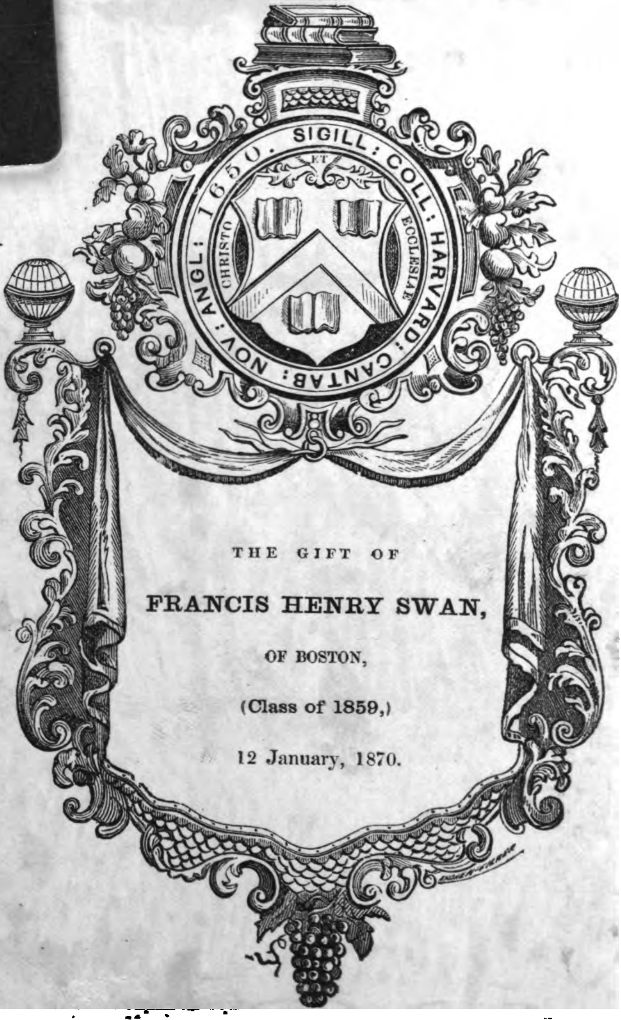
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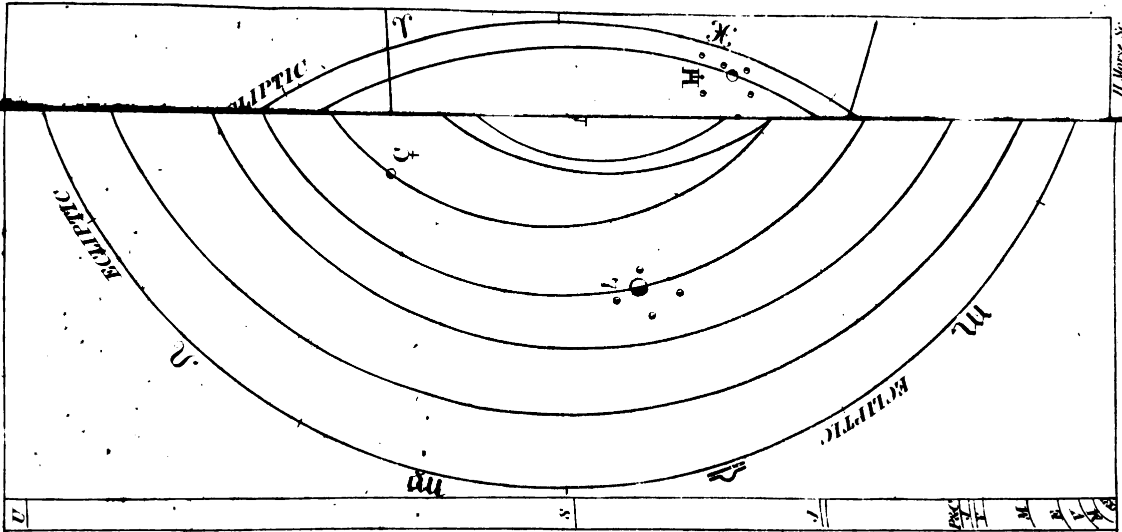

Proportional Distances of the Planets from the Sun.

ELEMENTS

OF

ASTRONOMY,

ILLUSTRATED

With Plates,

FOR THE USE OF

SCHOOLS AND ACADEMIES,

WITH QUESTIONS.

Hubbard

BY JOHN H. WILKINS, A. M

> "I shall straight conduct you to a hill-side, laborious indeed at the first ascent; but else so smooth, so green, so full of goodly prospect and melodious sounds on every side, that the harp of Orpheus was not more charming."
>
> *Milton.*

STEREOTYPE EDITION.

BOSTON:
PUBLISHED BY HILLIARD, GRAY AND CO.

1836.

1870, Jan. 12.
Gift of
Francis H. Swan,
of Boston.
(H. C. 1859.)

RECOMMENDATIONS.

* * *

Mr. Wilkins' elementary work on astronomy appears to us to be made upon an excellent plan, in which he adopts the most recent and approved distribution of the subject. The several parts are arranged in a simple and clear method, and the leading facts and principles of the science judiciously selected and concisely stated. It contains much matter within a narrow compass, embracing such recent discoveries and results, as properly come within the author's plant It is well adapted to the purposes of instruction, and will, we have no doubt, be found to be very convenient and useful by those teachers, who may put it into the hands of pupils of an age and previous attainments to qualify them for this study.

ELISHA CLAPP.
WILLARD PHILLIPS.

Dear Sir,

I have examined your treatise on astronomy, and I think that subject is better explained, and that more matter is contained in this, than in any other book of the kind, with which I am acquainted; I therefore cheerfully recommend it to the patronage of the public.

With respect, sir,
Your obedient servant,
WARREN COLBURN.

Mr. J. H. Wilkins.
Boston, 14 *June*, 1822.

Wilkins' Elements of Astronomy, by presenting in a concise, but perspicuous and familiar manner, the descriptive and physical branches of the science, and rejecting what is merely mechanical, exhibits to the student all that is most valuable and interesting to the youthful mind in this sublime department of human knowledge.

WALTER R. JOHNSON,
Principal of the Academy, Germantown.

Germantown, (Penn.) 5th June, 1823.

Having examined the work above described, I unite in opinion with Walter R. Johnson concerning its merits.

ROBERTS VAUX.

Philadelphia, 6th Mo. 11, 1823.

Messrs. Cummings, Hilliard, & Co.

Having been partially engaged in giving instruction to youth, for the last fifteen years, it has been necessary for me to examine all the treatises on education which came within my reach. Among other treatises examined, there have been several on Astronomy. Of these, the "Elements of Astronomy, by John H. Wilkins, A. M." recently published by you, is, in my opinion, decidedly the best. I have accordingly introduced it into my Seminary, and find it well calculated to answer its intended purpose, by plain illustrations to lead young persons to a knowledge of that most interesting science.

J. L. BLAKE,
Principal of Lit. Sem. for Young Ladies.

Boston, Jan. 5, 1825.

DIRECTIONS FOR PLACING THE PLATES.

COPPERPLATES.

Frontispiece to front title page.—All the rest in order at the end.

WOOD CUTS.

Relative sizes of the Planets,		Page 7
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" "	Mars,	17
" "	Jupiter,	20
" "	New Moon,	14

ADVERTISEMENT

TO THE SECOND EDITION.

The rapid sale of the first edition of this work, the author is willing to attribute to the obvious public *desideratum* of a work of this kind, rather than to any peculiar merit of his production. He is not the first, nor probably will he be the last, to form a more correct judgment of what the public need, than of his own ability to supply that deficiency. The encouragement which he has received, has, however, induced him to correct and somewhat enlarge his work. A great number of facts, omitted in the first edition, are noticed in this, both in the Descriptive and Physical part. To relieve the pupil from a dry narration of facts, or abstract illustration of principles, the author has subjoined to their proper sections and articles, a popular description of several of the most striking natural appearances and phenomena. He has also greatly increased the number of questions. Upon the whole, he feels confident, that the relative value of his work is not diminished by having its size increased.

Several instructers have suggested, that it might be useful to subjoin Tables for calculating eclipses. On this subject the author would only remark, that these Tables and the necessary instructions for applying them, would swell the work to a size, that would in a considerable degree defeat the objects of its publication.

Moreover, he cannot very highly appreciate the value of *mechanical rules* for calculating eclipses, while the *grounds* and *reasons* of those rules, and of the *tables*, to which they refer, are not understood; and nothing but mechanical rules can here be expected. To a vast majority of pupils, an understanding of the reasons and principles of these rules and tables would be much more useful than the ability to apply them.

It is an evil to have frequent alterations in school books of any kind. In some it is unpardonable. But it is a still greater evil to have a book remain imperfect, while it is in the power of the author to improve it, and the book is worth the labour. This is particularly true with regard to books like this. New facts in astronomy are continually coming into notice, which modify and limit the application of established principles. New *data* for intricate calculations are derived from constant observation. Hence many things, which we now suppose to be true or nearly so, may in a short time be found to be false, or true only under certain circumstances. New and happy illustrations of difficult subjects may also be suggested. All these will cause a difference in the different editions of the same work. The author, therefore, cannot promise that future editions shall not be "improved." He will, however, endeavour to make no alterations, which are not dictated by real utility.

Boston, Feb. 14, 1823.

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INTRODUCTION.

1. The first change in nature, which the eye, just opened upon the things of this world, notices, is that of light and shade, from day to night and from night to day. The beams of the morning awake the infant from the slumber of the cradle, and call him forth to activity and life; the twilight of the evening insensibly disengages his attention from objects of sight, and the darkness of night finds him again in repose. He soon walks forth under the heavens. He notices, that when darkness gives way to light, the sun becomes visible in the east; and that when the sun has passed through the heavens, he disappears in the west, and light gradually yields to darkness. At the same time that these changes are noticed by the eye, he feels that warmth or heat increases and decreases, much in the same manner, and in the same degree, that light does; and that at the same time that darkness steals one object after another from his sight, a sensation of cold pervades his frame. He soon comes to this conclusion, that the sun is the grand dispenser of heat and light; that the day is caused by his presence; and that the coldness and darkness of night are nothing but his absence.

2. Besides the changes of heat and cold which a single day exhibits, he will pass but a small part of the

ordinary age of man, before he becomes sensible of other changes. He observes a long succession of days and nights, during which the atmosphere is warm and comfortable to himself and all other animals, and the earth puts forth her thousand forms of vegetable life. By degrees the atmosphere is divested of its heat, the vegetable kingdom is stript of its foliage, and cold and snow succeed agreeable temperature and verdure. After some length of time, he beholds the earth again renovated, and nature again rejoicing in genial warmth. During these changes, the sun appears to move *northward*, and *southward*. By witnessing a few of these changes, he understands what is meant by *the seasons*, *Summer* and *Winter*, *Spring* and *Autumn*.

3. When the sun has *apparently* retired from creation, night presents its countless multitude of shining bodies. The most careless observer cannot long withhold attention to the ever varying *phases* of the moon. At one time, it is seen just after sunset, like half a ring. Gradually this ring fills up, or thickens, till in about a week, it becomes a semicircular surface. It continues to increase, till the surface becomes perfectly circular. It then decreases, as it had before increased, and for a short time is invisible; when it appears again as a part of a ring.

4. From the moon the eye glances to those bodies, which are known to youth as stars. The observations of a short period are sufficient to establish the *apparent* truth, that most of them are fixed and stationary, always preserving the same apparent distance and direction from each other; but that some of them are

wandering, continually changing their position with regard to other bodies apparently in their neighbourhood. The former are considered as *stars*, or *fixed stars;* the latter are *planets.* Occasionally a stranger appears, which unlike other heavenly bodies, is accompanied by a train or tail more or less luminous, and which, in a longer or shorter period, becomes again invisible. These are *comets.*

5. These observations, which are now familiar to the mind in youth, not to say in childhood, show that *all the heavenly bodies, except the stars, and perhaps the sun, are in motion.* From this single fact result all the changes in nature. To produce day and night, either the sun goes round the earth, or the earth turns so as to present different parts to the sun, in a day. To produce the seasons, either the sun actually moves northward and southward, or the earth has such a motion as to present the northern part to the sun in one season, and the southern part in another. The moon, planets, and comets, by changing their position with regard to the stars, and also to each other, must obviously have a motion. In manhood, the mind inquires into the nature and motions of the heavenly bodies; observes the various phenomena, which they present; and, as far as it is able, educes the laws, by which their motions are regulated. The Science, which explains these particulars, is called ASTRONOMY. It is divided into *descriptive Astronomy*, and *physical Astronomy*. The first includes an account of the phenomena of the heavenly bodies; the last explains the theory of their motions.

BOOK I.

DESCRIPTIVE ASTRONOMY.

CHAP. I.

SECT. 1. *Of the Solar System in general.*

6. THE *true* Solar system, or, as it is sometimes called, the *Copernican* system, consists of the sun and an unknown number of bodies opaque, like our earth; all of which bodies revolve round the sun, and some of which at the same time revolve round others. Those which revolve round the sun only, are called *primary planets* and *comets*. Those which revolve round a primary planet, at the same time that they are revolving round the sun, are called *secondary* planets *moons* or *satellites*. The number of primary planets is 11, viz. *Mercury*, *Venus*, *the Earth*, *Mars*, *Vesta*, *Juno*, *Pallas*, *Ceres*, *Jupiter*, *Saturn*, and *Uranus*. The number of the secondary planets, moons or satellites, is 18; the Earth has 1, Jupiter has 4, Saturn has 7, and Uranus has 6. The number of the comets is unknown.

7. The sun is in the centre of the system. *(See Frontispiece.)* The primary planets move round him in the order above named, at different distances and in different times, from west to east. *(It is to be noticed, that in all the figures referred to in this treatise, the upper part is south, the lower part north; the right hand west, and the left hand east.)* They are often distinguished, especially in almanacs, by the signs used in the

Frontispiece, viz. ☿ Mercury, ♀ Venus, ⊕ Earth, ♂ Mars, ⚶ Vesta, ⚵ Juno, ⚴ Pallas, ⚳ Ceres, ♃ Jupiter, ♄ Saturn, ♅ Uranus. The path, which a heavenly body describes in its revolution, is called its *orbit.* The secondary planets generally move round their primaries in the same direction, in which the primaries move round the sun. (*The small circle round the earth represents the moon's orbit. Each of the satellites of Jupiter, of Saturn, and of Uranus, describes an orbit round its primary, similar to that of the moon round the earth.*) Comets move in all directions. A part of a comet's orbit is represented in the Frontispiece.

8. Though in the Frontispiece the orbits of the planets are circles, yet this is not their true form. All the revolving bodies in the solar system move in orbits *oval* or *elliptical.* (Pl. I, fig. 2.) *ABDE* is an *ellipse*,* and represents the orbit of a planet, say of the earth. The points *S*, *s*, are called *foci* of the ellipse. The sun, instead of being in the centre *C*, is in one of the *foci*, as *S*. In like manner, when a secondary planet revolves round a primary, the primary is not in the centre of its orbit, but in one of its *foci*. That focus of an orbit, in which the sun or a primary planet is, is called the *lower* focus; and the other is called the *upper* focus. When any body, revolving round the sun, is nearest to him, as at *A*, it is said to be in its *perihelion;* and when it is most distant, as at *B*, it is said to be in its *aphelion*. When the moon is nearest the earth, it is said to be in *perigee;* when at its greatest distance, it is said to be in *apogee*. The line *SD* is the *mean* dis-

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* To describe an Ellipse, pin down the ends of a string upon a table or piece of paper, at any two places, as *S*, *s*. The string should not be drawn, but be left slack. Then with a pencil stretch the string as far as it will extend in every direction, and the point of the pencil will describe an *ellipse*. The points *S*, *s*, where the string is fastened, are the *foci*. The ellipse will always be more or less *eccentric* in proportion as the string is drawn more or less tightly.

tance of the orbit from the lower focus; *SC* is its *eccentricity*.

Though the orbits of the planets in the frontispiece are circles, yet they are not *concentric*, that is, have not the same centre. The centre of each orbit is placed out of the centre of the sun at a distance equal to the eccentricity of its true orbit. Each planet is placed in its aphelion.

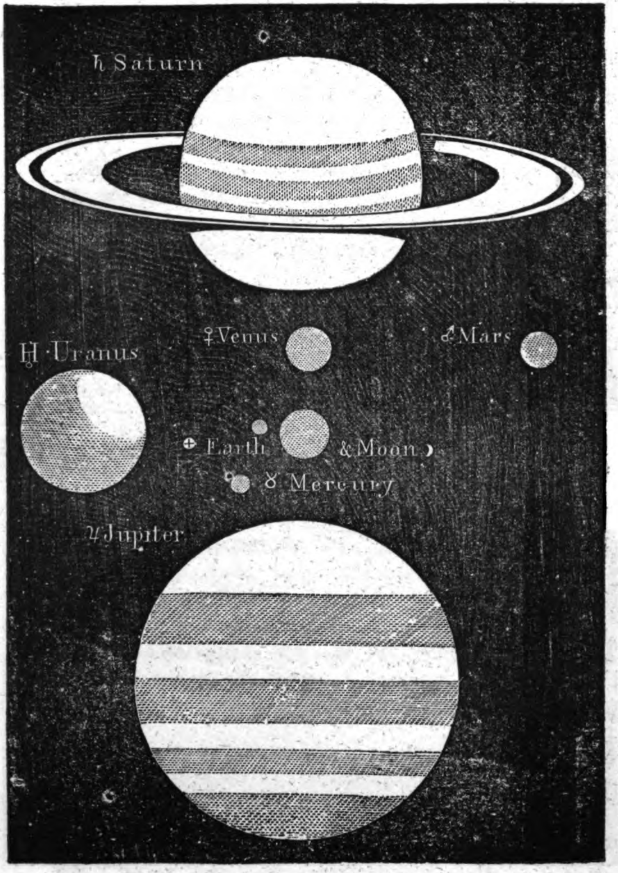
The relative distances of the primary planets from the sun could not be well preserved in this figure, but are represented in the margin.

9. The sun and all the planets, primary and secondary, are globular, though not perfect globes. This is known of all, except the earth, by their *always* appearing nearly round to the naked eye, or through a telescope. It is known of the earth, by its shadow on the moon in an eclipse, which is always circular. Pl. I, fig. 4, represents the relative magnitudes of seven of the primary planets and the moon, together with the ring of Saturn, which will be described hereafter. The diameter of the sun in relation to that of the planets, as here represented, is about one foot. The relative sizes of the same planets are represented on the accompanying wood-cut.

10. The sun and the primary and secondary planets, as far as astronomers have means and opportunity of ascertaining, turn on imaginary lines passing through their centres, which are called *axes*. The time, in which the heavenly bodies turn on their axes, is various; but generally the largest turn quickest. *A wire passing through the centre of an apple properly represents the axis of a planet. The extremities of an axis are called* POLES.

11. If the earth were seen from the sun, (Pl. I, fig. 1,) it would appear to describe a circle among the stars, while it revolves in its orbit. For while it is passing from *A* to *B*, it would be seen to move among the stars from *a* to *b*. And in like manner through its

RELATIVE SIZES OF THE PLANETS.



whole orbit. While the earth, viewed from the sun, would describe this circle among the stars, the sun, to us on earth, *appears* to describe precisely the same circle, only beginning at the opposite point. For while the earth actually moves from *A* to *B*, the sun *appears* to move from *c* to *d*; and while the earth moves from *B* to *C*, the sun *appears* to move from *d* to *a*, and so on. This path or circle, which the earth describes as seen from the sun, and which the sun *appears* to us to describe, is called the *ecliptic*; and a plane, passing through this circle, is called the *plane* of the ecliptic. (*The surface of the paper on which the figure is drawn, properly represents a* PLANE.) The ecliptic, and in fact all circles, whether great or small, are divided into 360 degrees (marked °), and each degree into 60 minutes, (marked ′), and each minute into 60 seconds, (marked ″), and so on into smaller divisions. The ecliptic has another division into 12 *signs*, containing of course 30° each. The division into signs, and the names of the signs are given in the figure, beginning with *Aries*, and reckoning through *Taurus*, *Gemini*, &c. Instead of the *names* of the signs, the characters prefixed to them in the figure, are often used. These characters are placed in the ECLIPTIC in the Frontispiece: by which it may be readily seen in what sign, and nearly in what part of a sign, is the aphelion of each planet. The English names of the signs, in order, are the *Ram*, the *Bull*, the *Twins*, the *Crab*, the *Lion*, the *Virgin*, the *Scales*, the *Scorpion*, the *Archer*, the *Goat*, the *Water-Bearer*, the *Fishes*.

The instructer should explain *degrees* to the pupil; show him, that they are not of any absolute determinate length, but vary as the circle is greater or smaller. This may be readily done by drawing two or three concentric circles, and a few lines from the centre to the outermost circle

12. But the other primary planets, when seen from

the sun, do not describe exactly the same circle among the stars, that the earth does; but are sometimes on one side of the ecliptic, and sometimes on the other. But none of them, except Juno, Pallas, and Ceres, are ever farther distant from the ecliptic than 8°. So that within a zone or belt of 16°, (8° on each side of the ecliptic,) the planets, except those just named, are always to be found. This zone is called the *Zodiac*. It is represented by the dark belt interspersed with stars, in the figure. The inner half represents the part beyond the ecliptic; the outer half, the part on this side. The points, where the orbit of any heavenly body cuts the plane of the ecliptic, are called the *nodes* of that body. The point, where the body passes from the north side of the plane of the ecliptic to the south, is called its *descending node;* where it passes from the south to the north, its *ascending node*.

In order that what has been said may be well understood, it may be necessary for the pupil to go over it again and again. Nothing should be passed over without being understood. Instructers should explain and illustrate what is obscure, and in many cases necessarily so. A familiar illustration will give a pupil a better idea of such things as *axis*, *plane*, *degree*, *focus*, and many others, than can be done in a dozen pages.

SECT. 2. *Of the Sun.*

13. The sun is the centre of the solar system, dispensing heat and light to all the various bodies, which continually move round him. Like the Centre of the universe, the sun is constantly imparting of its own to recipient subjects. All the bodies in our system, which revolve round him, impart no rays of their own, but are seen by his light reflected. In like manner in universal nature, we see reflected, the love and wisdom of the Lord. The different distances of the planets from

the sun occasion a reception of different degrees of heat and light. These are received according to the square of the distance of the planet from the sun; that is, *they decrease as the square of the distance increases.* Thus, if the distance of one planet from the sun be 1, and the distance of another be 2, and of a third be 3, the heat and light received at the first is 1 × 1 = 1, at the second 2 × 2 = 4 times less, or $\frac{1}{4}$, at the third 3 × 3 = 9 nine times less, or $\frac{1}{9}$.

14. The truth of this rule admits of familiar proof. (Pl. II, fig. 1.) Let *A* be a lamp, *BF* a square hole cut through a piece of pasteboard, placed at the distance of 1 foot from the lamp. Let the heat and light, which pass through the hole *BF*, fall upon a surface *CO*, at the distance of 2 feet from the lamp; it will be seen, that the surface *CO* is 4 times greater than the hole or surface *BF*; consequently, the heat and light at any point in *CO*, is 4 times less, than at a point in *BF*. But if there be a surface *DS*, at the distance of 3 feet, instead of *CO*, it will be found, that the heat and light passing through *BF* is diffused over a surface 9 times greater than *BF*; consequently, the heat and light at any point in *DS* is nine times less, than at a point in *BF*. Thus, as the square of the distance increases, heat and light decrease.

15. The sun does not always exhibit the same appearance. Dark spots are often seen on his *disk;* and sometimes, spots brighter than the rest of his surface. They appear to cross the disk from east to west; are alternately visible and invisible for the same length of time. Whence it is certain, that the sun turns on his own axis from west to east. The time of his rotation is little more than 25 days. The cause of these spots, which often change their size and figure, is not known.

16. The Zodiacal light is a singular phenomenon, accompanying the sun. It is a faint light which often

appears to stream up from the sun a little after sunset and before sunrise. It appears nearly in the form of a cone, its sides being somewhat curved, and generally but ill defined. It extends often from 50° to 100° in the heavens, and always nearly in the direction of the plane of the ecliptic. It is most distinct about the beginning of March; but is constantly visible in the torrid zone. The cause of this phenomenon is not known.

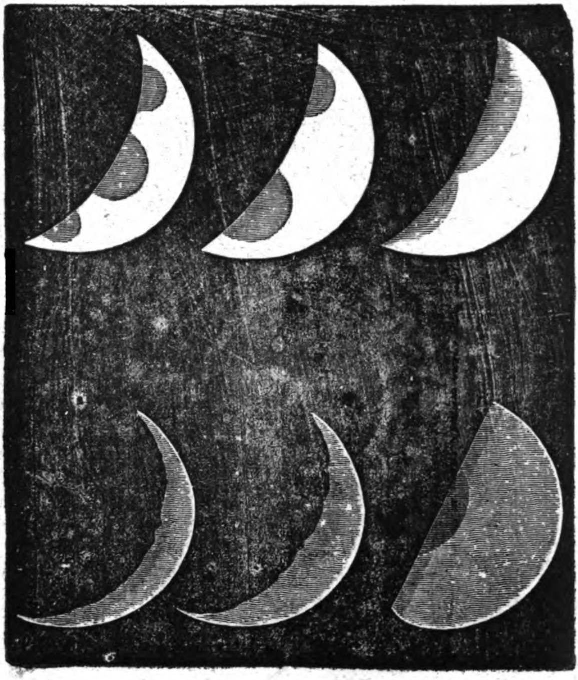
In Almanacks, the sun is usually represented by a small circle, with the face of a man in it.

Sect. 3. *Of Mercury.*

17. Proceeding from the sun, the grand centre of the system, the first planet is Mercury. It revolves round the sun at nearly the mean distance of 37 millions of miles, and completes its revolution in about 3 months. The time, in which it turns on its axis, is about 24 hours. It emits a brilliant white light; but because it is near the sun, and consequently seldom out of twilight, it is not often noticed. Its greatest apparent distance from the sun, or its *greatest elongation*, is never more than 28°. When viewed through a good telescope, it exhibits all the different appearances or *phases*, which the moon does, and they are to be accounted for in the same manner. Of this we shall treat hereafter.

18. The distance of Mercury from the sun is to that of the earth nearly as 3 to 8. Therefore the degree of heat and light at Mercury is to that at the Earth, nearly as (8 × 8) 64 to (3 × 3) 9; which is very nearly as 7 to 1. Consequently, at Mercury, heat and light are 7 times greater than with us. Water would there fly off in steam and vapour.

TELESCOPIC APPEARANCES OF VENUS.



SECT. 4. *Of Venus.*

19. Next to Mercury, in the Solar system, is Venus. This planet revolves round the sun at the mean distance of 68 millions of miles. It completes its revolution in about 7½ months; and turns on its axis in little less than 24 hours. The light reflected by this planet is very brilliant, and often renders it visible to the naked eye in the day time. Its greatest elongation is about 47°. It exhibits phases similar to those of Mercury and the moon. Spots are sometimes seen on its surface; the appearances of which, and its phases, are exhibited in the annexed wood-cut. Heat and light at Venus are nearly double what they are at the earth.

20. This planet is brightest, when she is about 40° distant from the sun; and then only about ¼ part of her disk is illuminated. Her brightness in this position is surprising. Her lustre far exceeds that of the moon, at the same apparent distance from the sun. For though, on account of her apparent magnitude, the moon reflects more light to us than Venus does, yet this light is incomparably more dull, and has none of the life and briskness which attend the beams of Venus. This difference arises probably from the circumstance of Venus having a very dense atmosphere, while the moon has a very rare one.

21. Mercury and Venus are called *interior* planets, because they are nearer the sun than the earth is; while those that are farther from the sun than the earth is, are called *exterior*.* They exhibit some peculiarities,

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* In most books on astronomy, what are here called *interior* planets, are styled *inferior*; and what are here called *exterior*, are there denominated *superior*. But why this distinction of *superior* and *inferior* was ever made, it is difficult to see. In what proper sense can the word *superior* be applied to Mars in comparison of the Earth or Venus? Since every natural blessing of existence is derived from the heat and light of the sun, we should suppose that planets would be

arising from their situation; but as Mercury is seldom seen, those of Venus only will be noticed. During a part of its revolution, Venus rises and sets before the sun; it is then called *morning star*. During another part of its revolution, it rises and sets after the sun; it is then called *evening star*.* (Pl. II. fig. 2.) Let *S* be the sun, *BDEC* the orbit of Venus, *A* the earth, *AL* a part of its orbit, while Venus is moving from *C*, (which point is called its *superior conjunction)* through *B* to *D*, it will appear to the inhabitants of the earth at *A* to be above, or eastward of the sun; it will consequently be visible after the sun has set. But while passing from *D*, (which point is called its *inferior* conjunction,) through *E* to *C*, it will appear below or westward of the sun, and will consequently set before the sun.

22. If the earth were stationary at *A*, it is obvious that Venus would be above the sun, and be evening star in half its orbit; and be below the sun, and be morning star in the other half. But because the earth is in motion, Venus is above and below the sun alternately, in much more of its orbit. For let Venus emerge above the sun at *C*, when the earth is at *A;* while it is coming through *B* to *D*, the earth passes from *A* to *F;* consequently Venus must pass from *D* to *d*, before it is seen below the sun. So while Venus moves from *d* to *x*, (half its orbit,) the earth has come to *o;* consequently Venus must move on from *x* to *v* before it emerges again above the sun. This effect is very much greater than is represented on the figure. For while Venus passes

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superior according to the degree of heat and light which they received; that is, according to their proximity to the sun. This distinction of *interior* and *exterior* is not new, though but few have adopted it; but being, (as I conceive,) much the most appropriate, I feel desirous of having it adopted.

* The Ancients called the *morning star*, *Phosphorus;* and the *evening star*, *Hesperus*. These names are now often used, especially in poetry.

from *C* to *D*, half its orbit, the earth, instead of passing through the small portion *AF*, has passed through nearly ⅓ of her orbit; through which, and considerably more, (because the earth's motion is constant,) Venus must pass before she is seen below the sun. It is found that Venus is morning and evening star alternately, during about 290 days; a period, considerably exceeding a complete revolution of that planet in her orbit.

SECT. 5.

ART. 1. *Of the Earth.*

23. The planet next to Venus in the solar system, is the earth, which we inhabit. It revolves about the sun at the mean distance of 93 millions of miles. It completes this revolution in a year, and turns on its axis in a day, or twenty-four hours. The consideration of the figure of the earth will be resumed when we come to treat of physical Astronomy; and the other phenomena relating to this planet will be continued in CHAP. II. and III.

ART. 2. *Of the Moon.*

24. The moon is a secondary planet, revolving round the earth in about 29½ days, and is carried with the earth round the sun once a year. Its distance from the earth is about 240,000 miles. It turns on its axis in precisely the same time that it performs its revolution round the earth.

25. The most obvious fact relating to the moon, is, that her disk is constantly changing its appearance; sometimes only a semicircular edge is illuminated, while the rest is dark; and at another time, the whole surface appears resplendent. The first appearance is

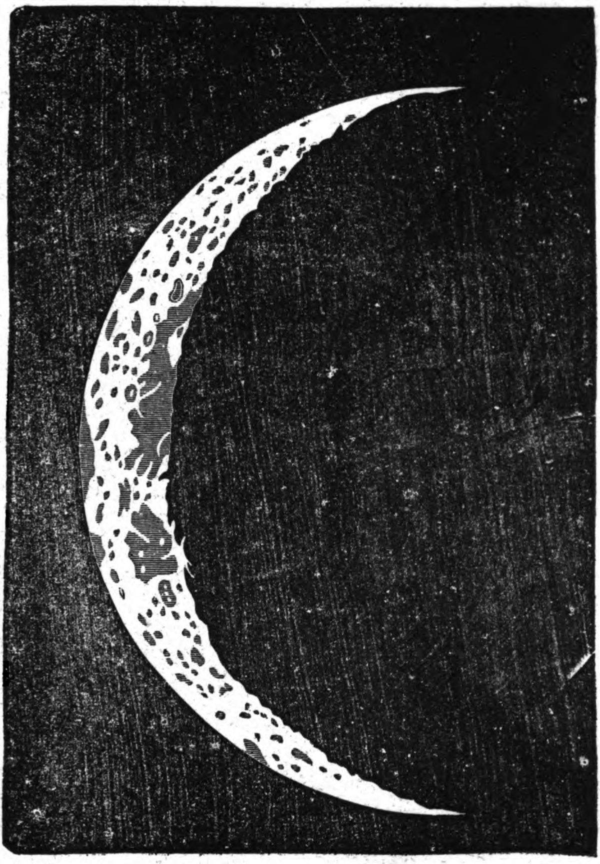
called the *new moon*, and is exhibited when the sun and moon appear near each other; that is, in the same region of the heavens. The second is called the *full moon*, and is exhibited when the sun and moon appear most distant; that is, in opposite regions of the heavens. When the moon is in *conjunction* with the sun, that is, passes by him, it is said *to change;* and when it is in *opposition* to the sun, that is, when the sun is in one part of the heavens, as west, and the moon in the opposite part, as east, the moon is said *to full*.

26. The different phases of the moon are easily accounted for. In Pl. II, fig. 3, let *S* be the sun, *E* the earth, and *ABCD* the moon in different parts of her orbit. When the moon changes, as at *A*, its dark side will be towards the earth, its illuminated part being always towards the sun. Hence the moon will appear to us as represented at *a*, if it be seen at all. But when she has advanced in her orbit, and come to *B*, a small part of her illuminated side comes in sight, and she appears as represented at *b*, a new moon, and is said to be *horned*. When she has come to *C*, one half her illuminated side is visible, and she appears as at *c*. At *C* and in the opposite point of her orbit, the moon is said to be in *quadrature*. At *D* her appearance is as represented at *d*, and she is said to be *gibbous*. At *E* all her illuminated side is towards us, and we have a full moon. During the other half of her revolution, less and less of her illuminated side is seen till it again becomes invisible at *A*.

The following signs are used in our common almanacs to denote the different positions and phases of the moon. ☽ or ☽ denotes the moon in the *first* quadrature, that is, the quadrature between change and full. ☾ or ☾ denotes the moon in the *last* quadrature, that is, the quadrature between full and change. ○ denotes new moon. ● denotes full moon.

27. The earth, seen from the moon, exhibits precisely the same phases that the moon does to us; only

TELESCOPIC APPEARANCES OF THE NEW MOON.



in an opposite order. When the moon is full to us, the earth will be dark to the inhabitants of the moon; and when the moon to us is dark, the earth to them is full. The earth appears to them about 13 times larger than the moon does to us. But as the moon turns on its axis in the same time that it goes round the earth, she always exhibits the same side to us; consequently we never see one half of the moon's surface, and the earth is never seen by that portion of the moon's inhabitants who dwell there.

28. When viewed through a telescope, the surface of the moon appears wonderfully diversified. Large dark spots, which are excavations or valleys, are visible to the eye; also some, which are even more lucid than the general surface. These are ascertained to be mountains, by the shadows which they cast. Maps of the moon's surface have been drawn; on which most of these valleys and mountains are delineated, and names are given to them. Some of these excavations are thought to be 4 miles deep and 40 wide. A high ridge generally surrounds them, and often a mountain rises in the centre. These immense depressions probably very much resemble what would be the appearance of the earth at the moon, were all the seas and lakes dried up. Some of the mountains are supposed to be volcanic.

Dr. Brewster, speaking of the Moon, says, "Her mountainous scenery bears a stronger resemblance to the towering sublimity, and the terrific ruggedness of Alpine regions, than to the tamer inequalities of less elevated countries. Huge masses of rock rise at once from the plains, and raise their peaked summits to an immense height in the air, while projecting crags spring from their rugged flanks, and threatening the valleys below, seem to bid defiance to the laws of gravitation. Around the base of these frightful eminences, are strewed numerous loose and unconnected fragments, which time seems to have detached from their parent mass; and when we examine the rents and ravines which accompany the over-hanging cliffs, we expect every moment that they are to be torn from their base, and that the process of destructive separation which we had only contemplated in its effects, is about to be exhibited before us in tremendous reality. The mountains, called the Apennines, which traverse a portion of the moon's disk from north-east to south-west, rise with a precipitous and craggy front from the level of the Mare Imbrium. In some places, their perpendicular elevation is above four miles; and though they often descend to a much lower level, they present an inaccessible barrier to the north-east, while on the south-west they sink in gentle declivity to the plains.

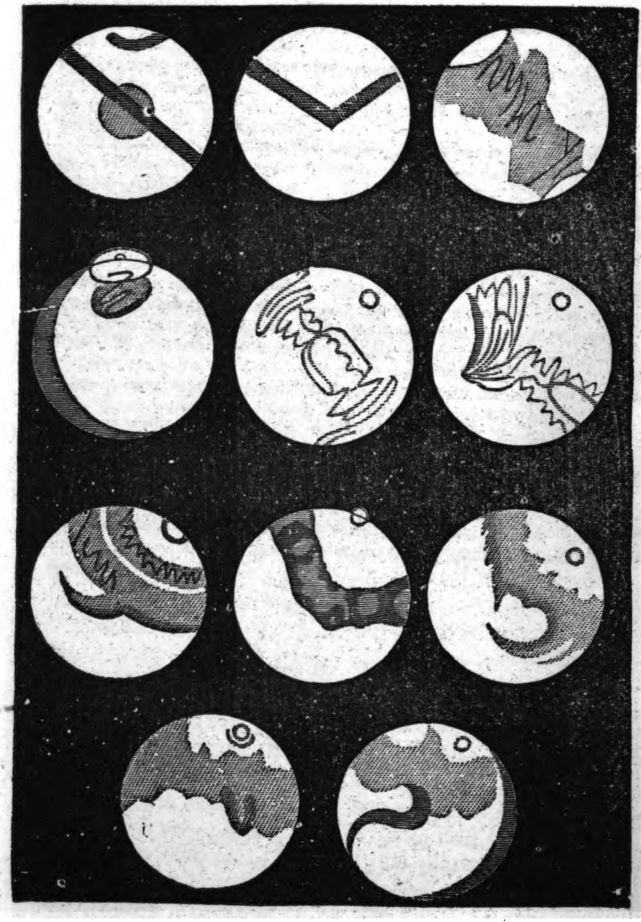
"The analogy between the surface of the earth and the moon fails in a still more remarkable degree, when we examine the circular cavities which appear on every part of her disk. Some of these immense caverns are nearly four miles deep and forty miles in diameter. A high annular ridge, marked with lofty peaks and little cavities generally encircles them: an insulated mountain frequently rises in their centre, and sometimes they contain smaller cavities of the same nature with themselves. These hollows are most numerous in the south-west part of the moon; and it is from this cause, that that portion of this luminary is more brilliant than any other part of her disk. The mountainous ridges which encircle the cavities, reflect the greatest quantity of light: and from their lying in every possible direction, they appear, near the time of the full moon, like a number of brilliant radiations, issuing from the small spot called Tycho.

"It is difficult to explain, with any degree of probability, the formation of these immense cavities; but we cannot help thinking, that our earth would assume the same figure, if all the seas and lakes were removed; and it is therefore probable, that the lunar cavities are either intended for the reception of water or that they are the beds of lakes and seas which have formerly existed in the moon. The circumstance of there being no water in the moon is a strong confirmation of this theory."

SECT. 6. *Of Mars.*

29. Next to the earth is the planet Mars. It revolves in its orbit in little less than two years, at the distance of 144 millions of miles from the sun; and turns on its axis in little less than 25 hours. The light reflected by Mars is remarkably red. Spots and sometimes belts have been seen on the disk of this planet, some of which are permanent, and others variable. Some of the most remarkable appearances of this kind, as they are seen through a telescope, are represented in the annexed wood-cut. These variations are supposed to arise from

TELESCOPIC APPEARANCES OF MARS.



clouds and vapours floating in the atmosphere. The degree of heat and light at Mars is something less than one half what we enjoy.

Sect. 7. *Of Vesta, Juno, Pallas, and Ceres.*

30. Next to Mars in the solar system is Vesta. It was discovered by Dr. Olbers, of Bremen, March 29, 1807. Its light is pure and white; and renders the planet visible to the naked eye. It revolves round the sun at the mean distance of about 223 millions of miles, in about 3 years and 8 months. The time of turning on its axis is not known.

31. Juno, the planet next to Vesta, was discovered by Mr. Harding, near Bremen, September 1, 1804. Its colour is red, and its atmosphere appears cloudy. Its mean distance from the sun is about 253 millions of miles. Its orbit is very elliptical; so that its greatest distance from the sun is nearly double its least distance, and the time of passing through one half its orbit is about double the time of passing through the other half. It completes its revolution in about 4 years and 4 months, and is supposed to turn on its axis in about 27 hours.

32. Pallas was discovered by Dr. Olbers, March 28, 1802. It appears to have a dense cloudy atmosphere. It revolves round the sun in an orbit nearly as elliptical as that of Juno, in about 4 years and 7 months, at the mean distance of 263 millions of miles. The time of turning on its axis is not known.

33. Ceres was discovered, at Palermo, in Sicily, by Piazza, January 1, 1801. Its mean distance from the sun is about the same as that of Pallas; but its orbit is less elliptical. It is of a ruddy colour. It revolves round the sun in very nearly the same time that Pallas does; and, what is very remarkable, its orbit intersects that

of Pallas. All these planets undergo various changes in appearance and size; so that their real magnitude is not ascertained with any certainty.

These four planets have been very recently discovered, and but little is known of them as yet. They are certainly very small. In the *Table* at the close of this CHAP. their *probable* size is given, except that of Vesta. It is a remarkable fact, that some irregularities, observed in the motions of the old planets, induced some astronomers to suppose that a planet existed between the orbits of Mars and Jupiter; a supposition that arose long previous to the discovery of the four new planets, which we have just noticed. The opinion has been advanced, that these four small bodies originally composed one larger one, which, by some unknown force or convulsion, burst asunder. This opinion is maintained with much ingenuity and plausibility by Dr. Brewster in the Edinburgh Encyclopedia, *Art.* ASTRONOMY. Dr. Brewster further supposes, that the bursting of this planet may have occasioned the phenomena of the meteoric stones; that is, stones which have fallen on the earth from the atmosphere.

SECT. 8. *Of Jupiter.*

34. Jupiter revolves at the mean distance of 490 millions of miles from the sun. It completes its revolution in little less than 12 years, and turns on its axis in the short time of 9 hours and 56 minutes. It is the largest planet yet discovered in the solar system, being 89,000 miles in diameter. It reflects a beautiful light, and is the most brilliant of the planets, except Venus. The degree of heat and light at Jupiter is about 25 times less than at the earth.

35. When viewed through a telescope, Jupiter exhibits an appearance somewhat different from any of the above planets. Generally several belts or bands are distinctly seen, sometimes extending across his disk, and sometimes interrupted and broken. These belts are variable in distance and position as well as number. They are generally dark, but white ones have been seen. Their appearances through a telescope are represented

in the annexed wood-cut. Both bright and dark spots have been seen in them; some of which revolve faster than others, which shows that they cannot be permanent spots on the body of the planet.

36. Jupiter is accompanied by 4 moons or satellites. These moons revolve round Jupiter as the moon does round the earth. Their revolutions are completed in different times; the shortest being less than 2 days, and the longest less than 17 days. These satellites often pass behind the body of the planet, and also into its shadow, and are eclipsed. These eclipses are of use in ascertaining the longitude of places on the earth, as will be shown hereafter. For this reason astronomers have taken great pains to calculate the precise time when they take place at London. By these eclipses it is also ascertained that light is about 8 minutes coming from the sun to the earth. For an eclipse of one of these satellites appears to us to take place 16 minutes sooner, when the earth is in the part of her orbit nearest Jupiter, than when in the part farthest from him. Hence light is 16′ in crossing the earth's orbit, and of course 8′ in coming from the sun. The satellite nearest to the primary is reckoned 1st, and the others, 2d, 3d, &c. as they are farther from the primary. The first satellite is somewhat less than the 2d, and the 2d somewhat less than the 4th, which is about as large as our moon; but the 3d is about twice the size of our moon.

37. On account of the immense distance of this planet from the sun, and also from Mercury, Venus, the Earth, and Mars, observers on Jupiter, with our eyes, could never see either of the above named planets, for they are always immersed in the sun's rays. They would direct their observations to planets which lie beyond; and here we know not the advantages of a position on Jupiter over one on the earth. For we know not how many planets belonging to our system,

within or beyond the orbit of Saturn or of Uranus, are distinctly visible at Jupiter, whose feeble light for ever precludes their discovery by us.

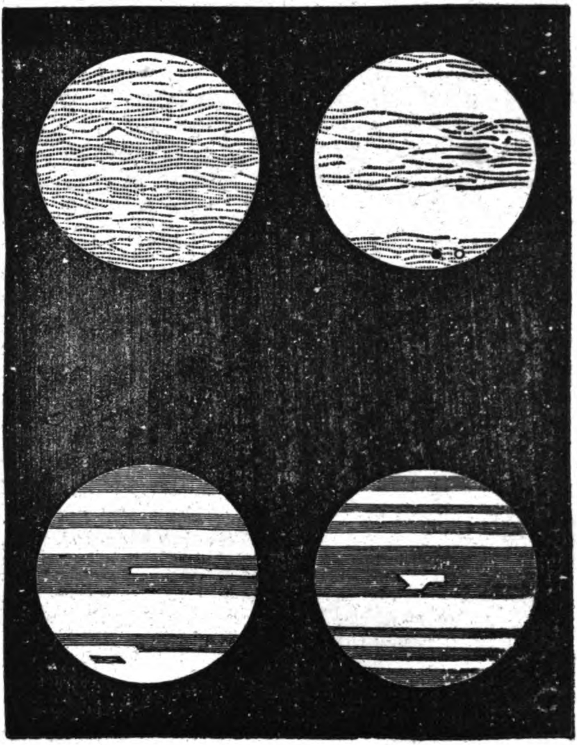
SECT. 9. *Of Saturn.*

38. Saturn, at the mean distance of 900 millions of miles, completes a revolution round the sun in little less than 30 years. It turns on its axis in little more than 10 hours. The light reflected by this planet is less brilliant than that of Jupiter. The degree of heat and light from the sun at Saturn is 80 times less than at the earth.

39. Saturn is remarkably distinguished from all the other planets in the solar system. When viewed through a telescope, it appears encompassed by a large luminous ring. This ring, in fact, consists of two, one exactly without or beyond the other. They are entirely detached from each other and from the body of the planet. *(They are represented* Pl. I, fig. 4, *and in the wood-cut, exhibiting the relative sizes of the planets.)* They cast a deep shadow, and appear even brighter than the planet; perhaps because they are above the region of mists and clouds in his atmosphere. They turn on the same axis with the planet, and in nearly the same time. Stars are sometimes seen between the rings, and also between the inner ring and body of the planet.

40. The surface of Saturn is sometimes diversified like that of Jupiter with spots and belts; which, like those, often vary. Saturn has 7 satellites, revolving at different distances, and in various times, from little less than 1 day to nearly 80. The nearest is reckoned 7th, the next 6th, the others 1st, 2d, &c. in order outward. The reason is, that the 7th and 6th are of recent discovery; the others have been long known.

TELESCOPIC APPEARANCES OF JUPITER.



SECT. 10. *Of Uranus.*

41. The planet Uranus was discovered by Dr. Herschel on the 13th March, 1781. Before that time, it had been seen by several astronomers. It was considered a small star, and was introduced as such into several catalogues of the stars. But Herschel first discovered it to be a planet. Its distance from the sun is about 1800 millions of miles. The time of performing a revolution is about 84 years. It is not known in what time it turns on its axis. Heat and light at Uranus are about 360 times less than with us. Uranus is scarcely visible to the naked eye.

42. This planet is attended by six satellites; all of which were discovered by Dr. Herschel, and revolve in orbits nearly perpendicular to that of their primary. Their motion is *apparently* retrograde; but this is probably an optical illusion, arising from the difficulty of ascertaining which part of their orbits inclines towards the earth, and which declines from it. They are reckoned like those of Jupiter.

This planet is not uniformly designated by the name Uranus. Its discoverer called it Georgium Sidus, and it is often called Herschel. But on the continent of Europe it has obtained the name Uranus. Different writers on astronomy use different names.

◆

43. It was stated (No. 24,) that the moon turns on its axis in precisely the same time that it performs its revolution round the earth. This is known from its always presenting to us the same side. For example, at its full it always exhibits the same spots in very nearly the same place. So also at the first or third quarter; that is, in quadrature. It has been observed, that when the seventh satellite of Saturn is to the eastward of that planet, its light becomes continually weaker till it is

scarce perceptible; which circumstance must arise from dark spots or regions of a nature to reflect little or no light, which extend in a great degree over the side then presented to us. Now, that this phenomenon should *always* occur, when this satellite is precisely in this position, it is necessary that it revolve round its own axis in the same time that it revolves round Saturn. In like manner, by observing periodical changes in the intensity of the light of Jupiter's satellites, Dr. Herschel infers, that they turn on their axes in the same time that they occupy in moving round Jupiter. Hence it appears to be a general law of satellites, that *they turn on their axes in the same time in which they revolve round their primaries.*

44. On this account, the inhabitants of secondary planets observe some singular appearances, which the inhabitants of primary planets do not. Those who dwell on the side of a secondary planet next to the primary will always see that primary; while those who live on the opposite side will never see it. Those, who always see the primary, will see it constantly in very nearly the same place. For example, those who dwell near the edge of the moon's disk, will always see the earth near the horizon, and those in or near the centre will always see it directly or nearly over head. Those who dwell in the moon's south limb will see the earth to the northward; those in the north limb will see it to the southward; those in the east limb will see it to the westward; while those in the west limb will see it to eastward; and all will see it nearer the horizon in proportion to their own distance from the centre of the moon's disk. Similar appearances are exhibited to the inhabitants of all secondary planets.

It may be necessary for young pupils, that the instructer should illustrate the reason of these appearances.

Sect. 11. *Of Comets.*

45. Besides the planets above described, there is another class of bodies revolving about the sun, which are called *comets*. They generally move in orbits very elliptical; at one time coming very near the sun, in some instances even nearer than Mercury, and again receding to a distance far beyond the orbit of Uranus. They were often noticed by the ancients; and were looked upon as harbingers of dire calamity, and as messengers of vengeance from heaven. But modern astronomers look upon them as bodies solid and opaque, like the planets; revolving round the sun, like them, and governed by the same laws; and therefore constituting a part of the solar system. They are generally distinguished from all other heavenly bodies, by a lucid train or tail. This tail always extends in a direction nearly opposite to the sun. It is of various lengths, sometimes scarcely to be seen, and sometimes extending through 90° or even 100°. So that when the comet sets in the west, its tail extends to the *zenith*, that is, the point directly over head.

46. The magnitude of comets has been observed to be very different. Many of them without the tail appear no larger than stars; while others have been seen immensely larger. One is said to have been visible at Rome in the reign of the emperor Nero, which was not inferior in *apparent* magnitude to the sun. The astronomer Hevelius also observed a comet in 1652, which did not appear to be less than the moon, though it was deficient in splendour; having a pale, dim light, and exhibiting a dismal aspect. Most comets appear to have a very dense atmosphere surrounding their bodies, which very much weaken the sun's rays that fall on them. But notwithstanding this, when the sky is clear, the solid body of a comet often reflects a very splendid light.

47. The number of comets belonging to the solar system is unknown. Above 500 have appeared since the commencement of the Christian era; and accounts of many more are extant. The orbits of the comets being very elliptical, their velocity in one part is much greater than in another. They are also turned out of their course, retarded and accelerated by the attraction of the planets. These circumstances, together with the difficulty of obtaining the elements of their orbits, render all calculations of their periodical times extremely uncertain.

Dr. Halley and Professor Encke are the only astronomers who ever successfully predicted the return of a comet; and these in single instances only. Of three sanguine calculations of Dr. Halley, one has proved correct, one has entirely failed, and one remains to be tested. Professor Encke, of Seeberg in Germany, made observations on a comet visible in 1819, and calculated its periodical time to be about 1200 days only. He predicted its return in 1822; but owing to its position it would not be visible in Europe or in the United States. According to his prediction it appeared in 1822, and was visible at the Islands in the South Pacific ocean. It is but a small body, passing in its perihelion within the orbit of Mercury, and in its aphelion, midway between the orbits of the newly discovered planets and that of Jupiter. It is not improbable that this body will ere long be classed with the planets.

The orbits of 98 comets, up to the year 1808, have been calculated from observations of the times at which they most nearly approached the sun; their distance from the sun and from the earth at those times; the direction of their movements; the places at which their orbits cut the ecliptic, and their inclination to it. The result is, that of these 98, 24 passed between the Sun and Mercury, 33 between Mercury and Venus, 21 between Venus and the Earth, 16 between the Earth and Mars, and 4 between Mars and Jupiter; that 50 of these comets moved from east to west; and that their orbits inclined at every possible angle to the ecliptic.

When comets are nearest to the sun, they often move with incredible velocity. Newton calculated the velocity of the comet of 1680, when nearest the sun, to be 880,000 miles an hour; and Mr. Squire, from data obtained since the days of Newton, has computed its motion to be 1,240,108 miles an hour.

The comet of 1758, the return of which was predicted by Dr. Halley, was looked upon with great interest by astronomers, *because its return was predicted.* But four revolutions before, in 1456, it was looked upon with the utmost horror. Its long tail spread consternation over all Europe, already terrified by the rapid success of the Turkish arms. Pope Callixtus, on this occasion, ordered a prayer, in which both the comet and the Turks were included in one anathema.

SECT. 12. *Of the Stars.*

48. All the heavenly bodies, of which we have not treated, are called stars; and except comparatively a few, which in a course of years, appear to change their places they appear to be *fixed,* retaining the same situation in relation to each other. Their number is unknown; but we are commonly very much deceived in the number visible to the naked eye. It is seldom that so many as 1000 are visible at once in the clearest night; but by looking at them *confusedly,* we imagine them to be much more numerous. They are classed into six magnitudes; the largest are of the first magnitude, and the smallest that can be seen by the naked eye, are of the 6th.

49. We have no certain means of ascertaining the distance of any body from the sun, which exceeds 200 thousand times that of the earth. But none of the stars come within that limit; so we cannot determine their real distance. It is generally supposed that a part, if not all the difference in the apparent magnitude of the stars is owing to a difference in their distances; the smallest being farthest off. Though the stars generally appear fixed, yet they all may have motion. For their distance being so immensely great, (in no instance less than 200 thousand times that of the earth, probably much

more in general,) a rapid motion might not perceptibly change their relative situation in two or three thousand years.

50. As telescopes are improved, other stars become perceptible, which before were invisible. Many stars also, which, to the naked eye, appear single, when seen through a telescope appear double, treble, or even quadruple. Some stars are subject to periodical variations in apparent magnitude, at one time being of the second or third, and at another of the fifth or sixth. Some have been noticed alternately to appear and disappear; being visible for several months, and again invisible. Several stars mentioned by ancient astronomers are not now to be found; and some are now observed, which are not mentioned in the ancient catalogues.

51. In a clear autumnal evening, a remarkably light broad zone is visible in the heavens, passing from north-east to south-west. This appearance is usually called the *Milky-way*, or *Galaxy*. It is generally supposed that this appearance is owing to an immense number of stars, which, from their apparent nearness, cannot be distinguished from each other. Dr. Herschel, in the course of ¼ of an hour, saw the astonishing number of 116,000 stars pass through the field of view of his telescope, while it was directed to the milky-way. Many whitish spots or tracts, called *nebulæ*, are visible in different parts of the heavens, which are supposed to be milky-ways at an inconceivable distance.

52. The stars are probably suns, around each of which revolve primary and secondary planets, as about our sun. It is certain that they do not reflect the light of the sun, as do the planets; for their distance is so great, that they would not in such case be visible. The sun, at the distance of a star, would certainly appear to us no larger than a star does. Stars are distinguishable from the planets by their twinkling.

53. The ancients, in reducing astronomy to a science, formed the stars into *constellations*, by applying names to particular clusters. This arrangement was effected very early, and is the most ancient monument of human skill. The choicest efforts of art, and the most wonderful productions of labour, the pride and ruin of empires of the greatest known antiquity, have passed away, while the constellations remain, telling of people still anterior. Orion, in nearly the middle of which is the yard *L*, and the Pleiades, commonly called the 7 stars, are mentioned in the book of Job, the oldest book of which copies are extant with us. The number of constellations among the ancients was about 50; the moderns have added about as many more. On the celestial globe, the largest star in each constellation is usually designated by the first letter of the Greek alphabet, and the next largest by the second, and so on. When the Greek alphabet is exhausted, the English alphabet, and then numbers, are used.

54. In the zodiac are 12 *constellations*, of the same names with the *signs* of the zodiac or ecliptic. But these constellations and signs do not coincide; but each constellation is now just about 30° or a sign, eastward of the sign of the same name. For example, the constellation Aries is 30° eastward of the sign Aries, and the constellation Taurus, 30° eastward of the sign Taurus, and so on. Thus the sign Aries lies in the constellation Pisces, the sign Taurus in the constellation Aries, the sign Gemini in the constellation Taurus, and so on. Hence the importance of distinguishing between the *signs* of the Zodiac, and the *constellations* of the Zodiac. The cause of their difference will be noticed hereafter.

Our observations of the stars and nebulæ, are confined principally to those of the northern hemisphere. Of the constellations near the south pole, we know but little; while every region and point in the northern hemisphere is as familiar to the astronomer, as the geography of his native village. The following beautiful and interesting extract is from Humboldt's *Personal Narrative* :—

"From the time we entered the torrid zone, we were never wearied with admiring, every night, the beauty of the southern sky, which, as we advanced the south, opened new constellations to our view. We feel an indescribable sensation, when, on approaching the equator, and particularly on passing from one hemisphere to the other, we see those stars, which we have contemplated from our infancy, progressively sink and finally disappear. Nothing awakens in the traveller a livelier remembrance of the immense distance by which he is separated from his country, than the aspect of an unknown firmament. The grouping of the stars of the first magnitude, scattered nebulæ, rivalling in splendour the milky way, and tracks of space remarkable for their extreme blackness give a particular physiognomy to the southern sky. This sight fills with admiration even those, who, uninstructed in the branches of accurate science, feel the same emotion of delight in the contemplation of the heavenly vault, as in the view of a beautiful landscape, or a majestic site. A traveller has no need of being a botanist, to recognise the torrid zone on the mere aspect of its vegetation; and without having acquired any notions of astronomy, without any acquaintance with the celestial charts of Flamstead and de la Caille, he feels he is not in Europe, when he sees the immense constellation of the Ship, or the phosphorescent clouds of Magellan, arise on the horizon. The heaven, and the earth, every thing in the equinoctial regions, assumes an exotic character.

"The lower regions of the air were loaded with vapours for some days. We saw distinctly for the first time the Cross of the south, in the sixteenth degree of latitude; it was strongly inclined, and appeared from time to time between the clouds, the centre of which, furrowed by uncondensed lightnings, reflected a silver light. If a traveller may be permitted to speak of his personal emotions, I shall add, that in this night I saw one of the reveries of my earliest youth accomplished.

"When we begin to fix our eyes on geographical maps, and read the narratives of navigators, we feel for certain countries and climates a sort of predilection, for which we know not how to account at a more advanced period of life. These impressions, however, exercise a considerable influence over our determinations; and from a sort of instinct we endeavour to connect ourselves with objects, on which the mind has long been fixed as by a secret charm. At a period when I studied the heavens, not with the intention of devoting myself to astronomy, but only to acquire a knowledge of the stars, I was agitated by a fear unknown to those who love a sedentary life. It seemed painful to me to renounce the hope of beholding those beautiful constellations, which border the southern pole. Impatient to rove in the equinoctial regions, I could not raise my eyes towards the starry vault without thinking of the Cross of the south.

"The pleasure we felt on discovering the southern Cross was warmly shared by such of the crew as had lived in the colonies. In the solitude of the seas, we hail a star as a friend, from whom we have long been separated. Among the Portuguese and the Spaniards peculiar motives seem to increase this feeling ; a religious sentiment attaches them to a constellation, the form of which recalls the sign of the faith planted by their ancestors in the deserts of the new world.

"The two great stars which mark the summit and the foot of the Cross having nearly the same right ascension, (see No. 64,) it follows hence, that the constellation is almost perpendicular at the moment when it passes the meridian. This circumstance is known to every nation, that lives beyond the tropics, or in the southern hemisphere. It has been observed at what hour of the night, in different seasons, the Cross of the south is erect, or inclined. It is a time-piece that advances very regularly near four minutes a day, and no other group of stars exhibits to the naked eye an observation of time so easily made. How often have we heard our guides exclaim in the savannas of Venezuela, or in the desert extending from Lima to Truxillo, 'Midnight is past, the Cross begins to bend!' How often those words reminded us of that affecting scene, where Paul and Virginia, seated near the sources of the river of Lataniers, conversed together for the last time, and where the old man, at the sight of the southern Cross, warns them that it is time to separate."

Many of the facts stated above, with some others relating to the bodies which compose the solar system, are arranged in the following tables, useful for reference, but not necessary to be learned.

TABLE I.

Of the Sun and Primary Planets.

	Dist. in mill.	Time of revolving round the Sun.	Time of turning on their Axis.	Diameter in miles.	The earth being 1. Bulk.	Heat and Light.	Density.	Greatest distance from the ecliptic.	Hourly motion, in miles.	Eccentricity. Mean Dist. 1.
SUN	**	* *	25.5 d.	883.217	1380000	* *	$\frac{1}{4}$	* *	* *	* *
Mercury	37	87.97.d.	24. h.	3123	$\frac{1}{15}$	6.68	2	7°40′	110.000	0.205
Venus	68	224.7"	23.36h.	7702	$\frac{8}{9}$	1.91	$1\frac{1}{4}$	3°23′	84.000	0.007
Earth	93	365.25"	24. h.	7916	1	1.	1	0	68.000	0.017
Mars	144	687.00"	24.64h.	4398	$\frac{7}{24}$	.43	$\frac{7}{10}$	1°50′	54.000	0.093
Vesta	223	1313.00"	unkn.	unkn.	unkn.	.18	unk.	7°9′	45.000	0.097
Juno	253	1586.00"	†27. h.	†1545	†$\frac{1}{133}$	.14	unk.	13°	42.000	0.254
Pallas	263	1680.00"	unkn.	†2280.	†$\frac{1}{42}$	.13	unk.	34°30′	41.000	0.246
Ceres	263	1980.00"	unkn.	†1761	†$\frac{1}{80}$	.13	unk.	10°30′	41.000	0.076
Jupiter	490	4332.60"	9.94 h.	89170	1400	.037	$\frac{23}{100}$	1°19′	30.000	0.048
Saturn	900	10759.0"	10.27h.	79042	1000	.011	$\frac{9}{100}$	2°29′	22.000	0.056
Uranus	1800	30688.0"	unkn.	35100	90	.0027	$\frac{1}{5}$	0°49′	15.000	0.047

Those figures marked † are not certain.

TABLE II.

Of Secondary Planets.

Of the Moon.

Dist. from the Earth.	Inclin. of orbit to the eclip.	Revolution round the Earth.
Miles.	° ′	d h ′
240,000	5 50	27 7 43

Moon's diameter 2159. Bulk (that of the earth being 1) 1—49.

Period from change to change, 29d. 12h. 44′.

Of the Satellites of Jupiter.

	Distance from Jupiter.	Inclination of orbits to the orbit of Jup.	Revolution round Jupiter.
	Miles.	° ′ ″	d h ′
I	264.490	3 18 38	1 18 27
II	420.815	3 18 0	3 13 14
III	671.234	3 13 58	7 3 42
IV	1.180.582	2 36 0	16 16 32

Of the Satellites of Saturn.

	Dist. from Saturn.	Inclin. of orbits to the orbit of Sat.	Rev. round Saturn.
		°	d h ′
VII	119.627	30	0 22 37
VI	153.496	30	1 8 53
I	190.044	30	1 21 18
II	243.449	30	2 17 44
III	240.005	30	4 12 25
IV	788.258	30	15 22 41
V	2.297.541	42 45′	79 7 54

Of the Satellites of Uranus.

	Dist. from Uranus.	Inclin. of orbits to the orb. of Uran.	Rev. round Uranus.
		° ′ ″	d h ′
I	224.155	99 43 53 or 80 16 7	5 21 25
II	290.821	do.	8 16 57
III	339.052	do.	10 23 4
IV	388.718	do.	13 10 56
V	777.481	do.	38 1 48
VI	1.555.872	do.	107 16 40

CHAP. II.

LATITUDE AND LONGITUDE.

55. When *latitude* and *longitude* are applied to places on the earth, they properly belong to geography. But as the method of finding them is purely astronomical, it is proper to treat of them as used both to designate the situation of places on the earth, and of the heavenly bodies. Before any thing can be understood of latitude and longitude, definite ideas must be obtained of the *poles*, the *equator*, *parallels* of latitude, and *meridians*. The earth turns round on an imaginary line, passing through its centre, called its axis; the extremities of this axis are, as before stated, called *poles;* one *north* pole, the other *south*. If the axis be supposed to extend both ways to the starry heavens, its places or points among the stars are the *celestial* poles, one north, and the other south, directly over or beyond the poles of the earth of the same name. The north celestial pole is very near a particular star, which on that account is called the *pole star*.

56. The equator is a circle surrounding the earth from west to east, at equal distance from the poles. Hence the equator divides the earth's surface into two equal parts, called *hemispheres*. If the plane of the equator were extended every way to the starry heavens, the circle it would make among the stars is called the *celestial equator*. It is from the equator that latitude on the earth is reckoned. All places between the equator and the north pole are in north latitude, and all places between the equator and the south pole are in south latitude. The latitude is greater, as the place is farther from the equator and nearer the poles. All circles, passing round the earth from west to east between

the equator and the poles, are called *parallels of latitude;* and when two places, as Boston and Philadelphia, differ in latitude, they are said to be on different parallels. There may be as many parallels as there are places not equally distant from the equator.

57. A line passing over the earth from the north to the south pole, and crossing the equator at right angles, is called a meridian. Every place on the earth's surface may be supposed to have such a line or circle passing through it; consequently, when a place lies more easterly or westerly than another, it is said to have a different meridian. Hence there may be as many meridians, as there are places lying eastwardly and westwardly of each other. When places are on different meridians, they are said to be in different longitude. *Celestial* meridians are lines passing among the stars from one celestial pole to the other, crossing the celestial equator at *right angles.* When it is noon at any place, the sun is in the celestial meridian directly over the meridian of that place.

Let the instructer explain right angles.

58. To illustrate what has been said, let Pl. III. fig. 1. represent the earth. The line *NS* is its axis; the extremities of which, *N* and *S*, are the north and south poles of the earth. *EQ* shows the equator. The lines 10 10, 20 20, 30 30, &c. are parallels of latitude; and the lines *NAS*, *NBS*, &c. are meridians. If each of these meridians be supposed to extend quite round the earth, (as they do on the artificial globe,) each would divide it into an eastern and western hemisphere; just as the equator divides it into northern and southern.

Much of what is said in this chapter may be illustrated with a terrestrial and celestial globe, if at hand, far better than by any figure.

59. Latitude and longitude are expressed in degrees

and minutes. The latitude of a place on the globe is estimated by the number of degrees on its meridian between the equator and that place. For example, the place *x* is in latitude 40° north, because 40° of its meridian lie between the equator and it. The longitude of one place from another is determined by the number of degrees there are on the equator, between the meridian of one and the meridian of the other. For example, the place *v* is 20° west longitude from *x*, and *x* is 20° east longitude from *v*, because 20° of the equator lie between the meridians of *v* and *x*; as may be seen by the figures under the equator.

60. Of all the lines or circles passing round the earth from west to east, it is obvious that the equator is the only one which constitutes *a great circle*, that is, *divides the earth's surface into two hemispheres*. All the rest are *less circles*, that is, *divide the earth's surface into two unequal parts;* and more unequal as the circles are farther from the equator and nearer the poles. On this account it is much more natural to reckon latitude from the equator than from any other line or circle. But all the meridians are great circles, each dividing the earth's surface into two hemispheres. Hence there is no natural reason why longitude should be reckoned from one meridian rather than from another. Hence it was customary, till very lately, for writers of different nations to estimate longitude from different meridians, each selecting that of the capital of his own country as the first or *prime meridian*, and reckoning the longitude of all other places from this. Thus French writers estimated longitude from the meridian of Paris; British from that of London; American from that of Philadelphia, and afterwards of Washington. The obvious confusion and inconvenience of this practice at length induced writers in Europe and America to fix upon one prime meridian; and for this purpose selected that of

the Royal Observatory at Greenwich, near London. Hence, on most maps and charts recently published, longitude is laid down from the meridian of London or Greenwich.

61. The equator being once assumed as the circle from which to reckon latitude, the poles become natural limits beyond which it cannot be reckoned. For if latitude be reckoned beyond the poles on one side, the equator is approached on the other. Hence no place can have latitude exceeding 90°, the distance from the equator to the poles. Having agreed upon a certain meridian from which to reckon longitude both east and west, the opposite part of that meridian, continued round the earth, becomes the limit of longitude, which is obviously half a circle or 180° from the prime meridian. Hence no place on the earth's surface can have more than 180° longitude, and if a place has 180° longitude, it may be either east or west.

62. But the latitude and longitude of heavenly bodies are estimated somewhat differently from those of places on the earth's surface. It has been stated that the circle among the stars which the plane of the equator, extended every way to the starry heavens, would describe, is called the *celestial equator*. Now this celestial equator does not coincide with the ecliptic, but makes an angle with it of 23½°, that is, the earth's axis is not perpendicular to the plane of the ecliptic, but is inclined 23½°. (See Pl. V. fig. 1.) Thus we have two great circles, the ecliptic and equator, passing through the heavens eastwardly and westwardly, from which the latitude of the heavenly bodies might be estimated. Astronomers have selected the ecliptic for this purpose, and have supposed lines or circles to cross it at right angles, as the meridians do the equator; which lines or circles are called *secondaries* to the ecliptic. The points where all the secondaries to the ecliptic meet,

are called the *poles of the ecliptic;* which points are 23½° from the celestial poles.

This No. should be illustrated and explained to young pupils; familiar examples will readily occur to the instructer.

63. Hence the latitude of a heavenly body is its distance from the ecliptic, on a secondary to the ecliptic passing through it; and, like latitude on the earth, can never exceed 90°. The longitude of a heavenly body is the distance of a secondary to the ecliptic passing through it, from some uniform prime secondary. But the longitude of heavenly bodies, unlike longitude on the earth, is reckoned only *eastward;* consequently it may extend to 360°. It is usually stated in signs, degrees, minutes, &c.; and the prime secondary, from which it is reckoned, cuts the ecliptic in the beginning of the sign Aries, a point where the celestial equator crosses the ecliptic. Thus, if a secondary, passing through a heavenly body, cuts the ecliptic, say 18° in the sign Capricorn, the longitude of that body is 9 signs, 18°.

If a celestial globe be at hand, the pupil may be exercised in finding the latitude and longitude of some of the principal stars, &c. See Appendix, SECT. VIII. *Prob.* XIX.

64. But it is often important to know the distance of a heavenly body from the celestial equator, as well as from the ecliptic. This distance is its *declination,* and is reckoned on a meridian as latitude is on the earth. Its distance from the beginning of Aries, reckoned on the equator, is its *right ascension;* which, like celestial longitude, is reckoned through the whole circle, or 360°.

The learner should have a distinct idea of the difference between *celestial latitude* and *declination,* that one is reckoned from the ecliptic and the other from the equator. Also of *longitude* and *right ascension,* that one is reckoned on the ecliptic and the other on the equator; and both from the same point, viz. the beginning of Aries.

65. Let us return to the consideration of terrestrial

latitude and longitude. As the latitude of a place is its distance from the equator measured on its meridian, and all meridians are great circles and consequently equally large, it is obvious that a degree, or $\frac{1}{360}$ part, of one is equal to the same part of another. Hence degrees of latitude are all of the same absolute length, containing 60 geographical, or 69½ statute miles of 320 rods. Thus, if two places on the same meridian, whether near the equator or distant from it, differ in latitude 2°, their absolute distance from each other is $60 \times 2 = 120$ geographical miles, or $69\frac{1}{2} \times 2 = 139$ statute miles.

The statements in this No. are not *strictly* true, because the earth is not a perfect globe, as will be shown hereafter. But the earth is so nearly a perfect sphere, that it is always so represented on maps and globes.

66. With regard to longitude, the case is different. The equator is a great circle like a meridian; and a degree, or $\frac{1}{360}$ part of it, is equal to the same part of a meridian; and consequently a degree of longitude on the equator is equal to a degree of latitude. But the parallels of latitude are not great circles, but are continually becoming less as they are farther from the equator and nearer the poles. Consequently a degree, or $\frac{1}{360}$ part, of one parallel is not equal to the same part of another parallel, nor to the same part of the equator. For example, the places x and v are 20° apart (Pl. III. fig. 1.); but obviously they are not so many *miles* apart as they would be, if situated on the same meridians at the equator; and further apart, than if situated on the same meridians nearer the poles. Hence it is obvious, that *as latitude increases, the length of a degree of longitude decreases*; and when the latitude is 90°, longitude vanishes.

At the close of this Chapter is a Table, showing the length of a degree of longitude for every degree of latitude.

67. What has been said will enable us readily to find a place on a globe, map, or chart, *when its latitude and longitude are stated*. But the question forces itself upon us, how were the latitude and longitude first ascertained? I look on the map of the world, and find Boston placed in latitude about 42½° north, and in longitude little more than 70° west. But how did he, who first gave Boston this place, know that such was its *real* latitude and longitude? He could not go to the equator and measure its latitude; he could not go to London and measure its longitude. Or how can the latitude and longitude of a vessel be found, when driven about in the ocean and constantly changing its situation? The compass will show the mariner in what direction his vessel is going, but it will not show him the port he has left, nor that which he wishes to reach.

68. The *horizon* is the circle where the visible sky and land or water meet. For example, when the sun rises, he comes above the *horizon;* when he sets, he sinks below the *horizon*. When the plane of the horizon is supposed to just touch the earth's surface, the horizon is called *sensible;* but when the plane is supposed to pass through the earth's centre, the horizon is called *rational*. Thus, (Pl. I. fig. 3.) if *E* be the earth, the line *ab* represents the plane of the *sensible* horizon, and *cd* that of the *rational*. But the distance of the heavenly bodies is so great, that the difference between the sensible and rational horizon is not perceptible; and when they rise above or sink below the rational, they at the same time appear to rise above or sink below the sensible. We shall therefore for the present consider them as one; but uniformly, when the word *horizon* occurs in this treatise, the rational is meant, if the sensible be not stated. When a distinct idea of the horizon is obtained, it will be obvious, that *the zenith*, or point directly over head *is always exactly* 90° *from*

every part of the horizon. The *nadir* is the point in the heavens exactly opposite to the zenith.

The *Zenith* and *Nadir* are sometimes called the *poles of the horizon;* they being to the horizon, what the celestial poles are to the equator.

69. *The zenith of any place is just as many degrees from the celestial equator, as that place is from the earth's equator.* Let *SENQ* be the earth, (Pl. II. fig. 4.) *SN* its axis, and *EQ* the equator. Let *e g* * be 90° of a circle in the starry heavens, equal to *E o N*, 90° of a meridian on earth. To a person at *E* on the earth's equator, the point *e*, in the celestial equator, will be in the zenith. If the person move from *E* through *o* to *N* (90°), every successive point in *e g* * (90°), will come into the zenith; so that when he comes to *N*, * will be in the zenith. And in like manner, if he move through any part, as *Eo*, (40°), the zenith will be at *g*, 40° from the celestial equator. *Hence* it is obvious, that *if the distance of the zenith of any place from the celestial equator can be found, it will show the latitude of that place.*

70. It is to be noticed, that as a person changes his latitude, the plane of the horizon changes its position. For example, to a person at *E*, on the equator, the line *DSN** will represent the plane of the horizon; and both the terrestrial and celestial poles will be in the horizon. But if he move from the equator towards either pole, say *N*, and come to *o*, then the plane of the horizon is represented by the line *HO*. Here the pole star * will not be in the horizon, but above it; and just as far above it as the zenith *g* is from the celestial equator *e*. For the horizon is always just 90° every way from the zenith. Hence it is just as far from *g* to *d*, as from *e* to *; consequently just as far from * to *d*, as from *g* to *e*. Therefore, *in order to find the distance of the zenith of any place from the celestial equa-*

ter, (which is just the same as the latitude of that place,) *it is only necessary to measure the height of the celestial pole above the horizon.* This can be readily done by an instrument called *a quadrant.*

In order to show how the *altitude*, or height of a heavenly body above the horizon, can be ascertained, let *A a e* (Pl. III. fig. 2.) be a *quadrant*, that is a quarter of a circle: its circular edge being divided into 90°, and each degree, when practicable, divided into minutes, &c. Let *o, o,* be small sight-holes, and *A v*, a plumb-line, hanging loose from the point *A*. Let *1 be in the horizon, and *2 in the zenith. It is obvious, that, when the quadrant is so held that the *1 in the horizon is seen through the sights *o, o,* the plumb-line will hang by the edge *A e*. But if the quadrant be turned gradually towards *B*, the plumb-line will successively intersect the divisions of the quadrant, 10, 20, 30, &c.; and when the zenith *2 is seen through the sights *o, o,* the plumb-line will coincide with the edge *A a*. Thus, while the eye directed through *o, o,* successively passes over 90° of the heavens, the plumb-line passes over 90° of the quadrant. And just so of any part. For example, if the *3, 40° above the horizon, be seen through *o, o,* the plumb-line intersects the 40th degree, on the divided or *graduated* edge of the quadrant.

The place of the north celestial pole is very nearly marked by the pole star; and the situation of the south is so well described, that little difficulty is experienced in ascertaining it.

71. But this method of ascertaining latitude can be practised only by night, when the stars are visible. This is sufficient on land; but at sea it is often necessary to find the latitude by day. This can be readily done by taking the height of the sun at noon, called its *meridian altitude.* For if the sun be in the celestial equator *e*, and a person at *o* notices with a quadrant its distance from *H*, the horizon, by subtracting this distance from *g e H*, (90°), the distance *g e*, or the latitude of *o*, is ascertained. But if the sun be not in the celestial equator, but have either north or south declination, this declination must be first found by a *nautical almanac* or a common globe, and added to or subtracted from the sun's meridian altitude. For *it is the height of the equator and not of the sun, which must be*

taken from 90°. For example, if the sun be at *r*, with a north declination of 5°, this 5° must be taken from the meridian altitude of the sun, and it gives the height of the celestial equator; which being taken from 90°, gives the latitude of *o*. But if the sun's declination were south in the above case, it must be added to the sun's meridian altitude. These methods of finding latitude are generally sufficient; but there are others which may be practised if necessary.

It may be useful to subjoin the following rule. *When the latitude and declination are both north or both south, the declination must be subtracted from the sun's meridian altitude; but if one be north and the other south, it must be added.*

72. A very common way of ascertaining longitude at sea will here be noticed, but not explained. It is by what is called the ship's *reckoning*. That is, the direction, in which the vessel sails is noted, and the distance that she sails is estimated by an instrument, called the *log*. Having the direction or the *course*, as it is called, and the distance, the latitude and longitude may be ascertained by a common *traverse table*. But this method is very inaccurate and not to be depended upon, on account of currents in the ocean, tempests and unequal force of winds. Hence navigators have recourse to heavenly bodies for this purpose.

73. When the sun, in his *apparent* daily course round the earth, comes to the meridian of any place, it is noon at all places on that meridian, after noon at all places eastward of that meridian, and before noon at all places westward of it. For as the *apparent* course of the sun is from east to west, it is obvious that he will come to the meridian of any place sooner, as that place lies more easterly; and later as it lies more westerly. In 24 hours, the sun *appears* to complete a revolution, *i. e.* to pass through the whole circle of the heavens or 360°. Consequently he appears to pass through

(360 ÷ 24) = 15° every hour. Hence, when it is noon at a particular place, as Boston, it will be 1 o'clock at all places on a meridian 15° east of that of Boston, and 11 o'clock at all places on a meridian 15° west of that of Boston. If the distance of two meridians be 30°, the difference of time is 2 hours, and so on.

74. Hence it is plain that as places differ in longitude, that is, are situated on different meridians, the clocks and watches of those places will show different hours at the same instant of absolute time; a difference of 15° always producing a difference of 1 hour in time. For example, Paris is 2½° east longitude from London. This difference at the rate of 1 hour for 15°, produces a difference of time of 9 minutes 22 seconds. Hence the clocks at Paris are 9 minutes 22 seconds faster than those of London; so that when it is noon at London it is 9 minutes 22 seconds past noon at Paris. So also the difference of longitude between London and Boston is 71° 4′; consequently the difference of time by the clocks at Boston and London is 4 hours 44 minutes 16 seconds. Hence when it is noon at Boston, it wants 15 minutes 44 seconds of 5 o'clock at London; and when it is noon at London it is 15 minutes 44 seconds after 7 in the morning at Boston.

75. Hence, if the difference of time, as shown by the clocks of two places, is known, the difference of longitude between them can be ascertained. Suppose I have a watch of such workmanship, and so well regulated, that it would always show the exact time at London; by this I can find my longitude. For by observing the precise time when the sun comes to the meridian where I am, I know it is 12 o'clock where I am; and by looking at my watch, I know what the time is at London. Then, by allowing 1 hour for 15°, I know my longitude.

76. To illustrate this, suppose I am sailing in the

Mediterranean sea, and wish to know my longitude. When the sun is exactly south, and I know it to be noon where I am, I find by my watch that it wants 20 minutes of 11 o'clock at London. The difference in time is 1 hour 20 minutes. I am, therefore, on a meridian 20° from that of London; and eastward, because it is noon where I am *before* it is at London. Again, suppose I sail from London for the West Indies. After a boisterous passage, during which no observations of the heavenly bodies could be taken, and it was impossible to keep the ship's reckoning, I fall upon a coast, but know not whether it be that of an island or of the American continent. When the sun is in the meridian, I find by my watch, that it is a trifle more than 7 minutes past 5 at London. By turning this difference of 5 hours 7 minutes into degrees, I find I am in longitude about 76° 45′, and this must be west, because it is noon where I am *later* than at London. But in this case when I have found my longitude, I have not determined the coast. For by reference to a chart or a map, I find I may be either on the coast of the southern part of the United States, of the Island Cuba, of Jamaica, or of the northern coast of South America. But by taking the sun's altitude at the same time, and thus finding my latitude, say 22° 30′ north, I ascertain which of these several coasts I am on; viz. that of Cuba.

77. The principal difficulty in ascertaining longitude by this method is, that no timepieces have yet been constructed, and none probably can be, which will measure time accurately, and without variation. Clocks, which move by weights and are regulated by pendulums, are most uniform in their movements. But the constant motion of the vessel entirely precludes their use at sea. Incredible pains have been taken to render watches and chronometers accurate measurers of

time; but variation in the temperature of the air renders their movements more or less irregular.

It is not always necessary to wait for the sun to come to the meridian, in order to know the time of day. It may be known by other ways, as by the rising and setting of the sun, and of stars near the equator.

78. Hence it is often desirable to correct timepieces at sea; and for this purpose eclipses of the moon are sometimes of use. For eclipses of the moon take place at precisely the same time to all to whom the moon is visible; which is not the case with eclipses of the sun, as will be shown hereafter. Thus, if I sail from London, having an almanac in which the precise time of the beginning or ending of a lunar eclipse is calculated for the time at London; if the moon is visible to me at the time of eclipse, by observing the time of its beginning or ending, I get the true time at London, and can correct my timepiece accordingly. For example, if, on a particular day, an eclipse of the moon is calculated to begin at 17 minutes past 11 in the evening, London time, and at sea I observe it begin at 12 minutes past 11 by my chronometer, I know the chronometer is 5 minutes too slow, that is, slower than London time, and I can correct it accordingly.

Though eclipses of the moon take place at the same instant to all spectators, it is difficult to tell the precise moment when they begin or end, as will be explained in its proper place.

79. Hence if eclipses were frequent, timepieces, by being often regulated, would generally show correct time. But it is only in comparatively few voyages, during his life, that the navigator has opportunity of witnessing a lunar eclipse. On this account astronomers have turned their attention to the eclipses of other bodies, and especially to those of the satellites of Jupiter. These eclipses, like those of the moon, take place at the same instant to all spectators, and are suf-

ficiently frequent for correcting timepieces at sea,—there being scarcely a day, during which one or more of these satellites is not eclipsed. But at present it appears impossible to realize the peculiar advantages, which these phenomena are calculated to afford. For the satellites of Jupiter are too small to be visible to the naked eye, and the motion of the vessel renders a telescope useless. Hence, although astronomers have taken great pains to calculate these eclipses, yet they seem to have added nothing to the customary means of finding longitude at sea.

80. There is a method of ascertaining the time at London by observing the moon's place. Tables are calculated, showing the distance of the moon from the sun and some fixed stars for every day at noon, and every three hours afterwards, London time. To explain the use of these tables, suppose on a particular day it is stated in them that the moon will be 65° eastward from the sun at 6 o'clock in the evening, London time. At sea I observe that the moon is not 65° eastward from the sun till 40 minutes past 7, by the time where I am. This difference of 1 hour 40 minutes gives a longitude of 25°; and this must be eastward, because the time where I am is later than that at London. To an astronomer, accustomed to the application of the necessary principles, this method of finding the longitude would be the most accurate. Tables of the moon's parallax have been lately calculated; so that this method of finding longitude is accommodated to the capacity of the mass of navigators, and is daily coming more into use. But on account of the moon's parallax, which will be explained hereafter, it has hitherto been difficult to apply these tables.

81. Notwithstanding these various methods of finding longitude, it is still very difficult. An easy, expeditious, and sure method of effecting this purpose is a great

desideratum. Such a discovery would constitute a new era in navigation, scarcely less important than that of the discovery of the mariner's compass. The English nation, to whom every facility in the improvement of commerce is particularly important, have used all suitable means to direct the attention of astronomers to this subject. By an act of parliament, passed 1714, the English government offered 20,000 pounds reward to any person who should discover a method of finding longitude at sea within 30 miles, or ½ a degree; 15,000 pounds, if within 40 miles, or ⅔ of a degree; and 10,000 pounds, if within 60 miles, or a degree. Mr. John Harrison, an eminent artist, obtained, at two different times, 20,000 pounds for improving chronometers. So exact was one of his construction, that it erred but 1 minute 54 seconds in 5 months, a mean daily error of ¾ second. By a new act of parliament, passed 1774, the greatest reward which can now be obtained is 10,000 pounds.

TABLE

Showing the length of a degree of Longitude for every degree of Latitude, in geographical miles.

Deg. Lat.	*Miles.*	*Deg. Lat.*	*Miles.*	*Deg. Lat.*	*Miles.*
1	59,96	31	51,43	61	29,04
2	59,94	32	50,88	62	28,17
3	59,92	33	50,32	63	27,24
4	59,86	34	49,74	64	26,30
5	59,77	35	49,15	65	25,36
6	59,67	36	48,54	66	24,41
7	59,56	37	47,92	67	23,45
8	59,40	38	47,28	68	22,48
9	59,20	39	46,62	69	21,51
10	58,18	40	46,00	70	20,52
11	58,89	41	45,28	71	19,54
12	58,68	42	44,95	72	18,55
13	58,46	43	43,88	73	17,54
14	58,22	44	43,16	74	16,53
15	58,00	45	42,43	75	15,52
16	57,60	46	41,68	76	14,51
17	57,30	47	41,00	77	13,50
18	57,04	48	40,15	78	12,48
19	56,73	49	39,36	79	11,45
20	56,38	50	38,57	80	10,42
21	56,00	51	37,73	81	09,38
22	55,63	52	37,00	82	08,35
23	55,23	53	36,18	83	07,32
24	54,81	54	35,26	84	06,28
25	54,38	55	34,41	85	05,23
26	54,00	56	33,55	86	04,18
27	53,44	57	32,67	87	03,14
28	53,00	58	31,70	88	02,09
29	52,48	59	30,90	89	01,05
30	51,96	60	30,00	90	00,00

CHAP. III.

82. In the short account given of the solar system in Chap. I, we attempted to describe the appearances of the various heavenly bodies, and to state such facts relating to them, as are known to exist. But there are many particular appearances and phenomena peculiar to each planet, arising *from its situation in the solar system, from its revolution on its axis, from its revolution round the sun together with the degree in which its equator varies from its ecliptic, (called the obliquity of the ecliptic,) from its atmosphere, and from its size.* These phenomena are of little use or interest to us, as they affect the inhabitants of other planets; but are of great use as they affect us. Hence we shall confine ourselves to such as relate to the earth, and are of constant observation.

SECT. I.

Of Phenomena arising from the situation of the Earth in the Solar System.

ART. 1. *Of the different apparent motions and magnitudes of the other planets.*

83. The primary planets seen from the sun always appear to move the same way, viz. from west to east, which is their *direct* motion. But as seen from any planet, all the rest appear to move from west to east part of the time, to be *stationary* part of the time, and to move from east to west part of the time; (which last is called *retrograde* motion. Pl. III. fig. 3.) Let *S* be the sun, *E* the earth, and *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, Venus in different points in her orbit. It is plain, that while Venus is passing from *d* to *f*, it will appear to move in the starry heavens in the direction from *o* to *n*, whe-

ther seen from the sun or the earth; consequently its motion will be direct. But while it is passing from *h* to *b*, it will appear to move from *m*, through *n*, *o*, to *p*, in a different direction, as seen from the earth, from that in which it appears to move, as seen from the sun; that is, its motion is retrograde, and directly contrary to what it was in the opposite part of its orbit. While it is passing from *b* to *c*, or from *g* to *h*, it is moving almost directly from or to the earth, and consequently it will appear nearly stationary among the stars. At *e* Venus is said to be in its *superior* conjunction, because it is beyond the sun; at *a* it is said to be in its *inferior* conjunction, because it is between the sun and earth. The motions and conjunctions of Mercury are like those of Venus.

84. It is obvious also, that while the motion of Venus is direct or retrograde to us on earth, the motion of the earth will be direct or retrograde to the inhabitants of Venus; for, while Venus passes from *h* to *b*, and is retrograde to us, the earth appears to move from *r* towards *s*, directly opposite to its motion as seen from the sun. But while Venus is moving from *d* to *f*, the earth will appear to move in the same direction as if seen from the sun, that is, from *v* towards *r*. So also while Venus appears to us stationary at and near her greatest elongation, the earth appears stationary to an inhabitant of Venus. When Venus is at *a*, the earth is in *opposition;* that is, in a part of the heavens directly opposite to the sun. But when Venus is at *e*, the earth is in *conjunction* with the sun. Now, *precisely the same motions which the earth exhibits to the inhabitants of Venus, each of the exterior planets exhibits to us.*

85. It is plain also, that from the earth's situation out of the centre of the solar system, the apparent magnitudes of the other planets vary; for common experience shows, that as objects are nearer they appear

larger. Hence, when Venus is nearest the earth, as at or near *a*, its magnitude must appear larger, than when at or near *e*. As the apparent magnitudes of other planets vary to us, that of the earth varies to them.

ART. 2. *Of Eclipses.*

86. The situation of the earth with regard to the moon, or rather of the moon with regard to the earth, occasions eclipses both of the sun and moon. Those of the sun take place when the moon, passing between the sun and earth, intercepts his rays. Those of the moon take place when the earth, coming between the sun and moon, deprive the moon of his light. Hence an eclipse of the sun can take place only when the moon changes, and an eclipse of the moon only when the moon fulls; for *at the time of an eclipse*, either of the sun or moon, *the sun, earth, and moon must be in the same straight line.*

87. If the moon went round the earth in the same plane in which the earth goes round the sun, that is, in the ecliptic, it is plain that the sun would be eclipsed at every new moon; and the moon would be eclipsed at every full. For at each of these times, these three bodies would be in the same straight line. But the moon's orbit does not coincide with the ecliptic, but is inclined to it at an angle of about 5° 20′. Hence, since the apparent diameter of the sun is but about ½ a degree, and that of the moon about the same, no eclipse will take place at new or full moon, unless the moon be within ½ a degree of the ecliptic, that is, in or near one of its nodes. It is found that if the moon be within 16½° of a node at time of change, it will be so near the ecliptic, that the sun will be more or less eclipsed; if within 12° at time of full, the moon will be more or less eclipsed.

88. It is obvious that the moon will be oftener within 16½° of a node at the time of change, than within 12° at the time of full; consequently there will be more eclipses of the sun than of the moon in a course of years. As the nodes commonly come between the sun and earth but twice in a year, and the moon's orbit contains 360°, of which 16½°, the *limit* of solar eclipses, and 12°, the *limit* of lunar eclipses, are but small portions, it is plain there must be many new and full moons without any eclipses.

89. Although there are more eclipses of the sun than of the moon, yet more eclipses of the moon will be visible at a particular place, as Boston, in a course of years, than of the sun. Since the sun is very much larger than either the earth or moon, the shadow of these bodies must always terminate in a point; that is, it must always be a cone. (See Pl. IV. fig. 1 and 2.) Let *S* be the sun, *m* the moon, and *E* the earth. The sun constantly illuminates half the earth's surface, that is, a hemisphere; and consequently he is visible to all in this hemisphere. But the moon's shadow falls upon but a part of this hemisphere; and hence the sun appears eclipsed to but a part of those to whom he is visible. Sometimes when the moon is at its greatest distance, its shadow *o m*, terminates before it reaches the earth. In eclipses of this kind, to an inhabitant directly under the point *o*, the outermost edge of the sun's disk is seen, forming a bright ring round the moon; from which circumstance these eclipses are called *annular*, from *annulus*, a Latin word for ring.

90. Besides the dark shadow of the moon *m o*, in which all the light of the sun is intercepted, (in which case the eclipse is called *total*,) there is another shadow *r C D s*, distinct from the former, which is called the *penumbra*. Within this, only a part of the sun's rays are intercepted, and the eclipse is called *partial*. If a per-

son could pass, during an eclipse of the sun from *o* to *D*, immediately on immerging from the dark shadow *o m*, he would see a small part of the sun; and would continually see more and more till he arrived at *D*, where all shadow would cease, and the whole sun's disk be visible. Appearances would be similar if he went from *o* to *C*. Hence the penumbra is less and less dark, (because a less portion of the sun is eclipsed,) in proportion as the spectator is more remote from *o*, and nearer *C* or *D*. Though the penumbra is continually increasing in diameter according to its length, or the distance of the moon from the earth, still, under the most favourable circumstances, it falls on but about half of the illuminated hemisphere of the earth. Hence by half the inhabitants on this hemisphere no eclipse will be seen.

91. But the case is different in eclipses of the moon. (Fig. 2.) The instant the moon enters the earth's shadow at *x*, it is deprived of the sun's light, and is eclipsed to all in the unilluminated hemisphere of the earth. Hence eclipses of the moon are visible to at least twice as many inhabitants as those of the sun can be; generally the proportion is much greater. Thus the inhabitants at a particular place, as Boston, see more eclipses of the moon than of the sun.

92. The reason why a *lunar* eclipse is visible to all to whom the moon at the time is visible, and a *solar* one is not to all to whom the sun at the time is visible, may be seen from the nature of these eclipses. We speak of the sun's being eclipsed; but properly it is the earth which is eclipsed. No change takes place in the sun; if there were, it would be seen by all to whom the sun is visible. But he continues to diffuse his beams as freely and uniformly at such times as at others. But these beams are intercepted, and the earth is eclipsed; but only where the moon's shadow falls, that is, on only

a part of a nemisphere. But in eclipses of the moon, that body ceases to receive light from the sun, and consequently ceases to reflect it to the earth. The moon undergoes a change in its appearance; and consequently this change is visible at the same time to all to whom the moon is visible; that is, to a whole hemisphere of the earth.

93. The earth's shadow (like that of the moon) is encompassed by a penumbra *C r s D*, which is faint at the edges towards *r* and *s*, but becomes darker towards *F* and *G*. The shadow of the earth is but little darker than the region of the penumbra next to it. Hence it is very difficult to determine the exact time when the moon passes from the penumbra into the shadow, and from the shadow into the penumbra; that is, when the eclipse begins and ends. But the beginning and ending of a solar eclipse may be determined instantaneously.

94. The shadows of all the planets (like those of the earth and moon) terminate in a point; and this point is always so near the body, that one primary planet can in no case enter into the dark shadow of another. But their penumbras continually become broader; and consequently one primary planet often passes through the penumbra of another. But the penumbra of the earth is so faint, that the passage of a superior planet through it is not perceptible to us.

95. Let *S* (Pl. IV, fig. 3,) be the sun, *E* the earth surrounded by the moon's orbit; let *NO* be the moon's nodes. It is plain that if the moon's nodes were always in the same places, each of them would be between the earth and sun once a year, or while the earth is revolving round the sun. For example, the node *O* is thus situated in the figure, and the node *N* would be, when the earth comes into the directly opposite point of its orbit. *Now there must be an eclipse of the sun as often*

at least as one of the moon's nodes comes between the sun and earth. For it has been stated, that if the moon be within 16½° of a node, as *O*, at the time of change, the sun will be eclipsed. That is, there are (16½×2) 33° between 1 and 2, within which if the moon be, at the time of change, the sun will be eclipsed. Now the earth moves round the sun, and causes the sun to *appear* to move round the earth (360°) in about 365 days; that is, through little less than 1° in one day. Consequently the sun would be little more than 33 days in passing (apparently) through 33° of the ecliptic, equal to 33° of the moon's orbit, or the distance from 1 to 2. But the moon is only 29½ days in passing from one change to another; so that the moon must always be at least once (it may be twice) between 1 and 2, while the sun is passing through the corresponding 33° of the ecliptic. Hence, were the nodes stationary, there would always be at least two solar eclipses every year.

96. But there may not be any eclipses of the moon during a year. For the shadow of the earth at *N*, between 1 and 2, falls upon the moon only when the moon is in a space of 24° (12° each side of the node) of the moon's orbit. And as the moon does not complete its revolution in 24 days, it may not necessarily be between 1 and 2 while the sun is passing through 24° in the opposite part of the ecliptic.

97. The moon's nodes are not stationary, but move backwards from east to west. So that if the node be at *O* at one change, it will be somewhere at 1 the next. Hence in some years a node is between the sun and earth three times. But this motion of the nodes is so slow, that they complete their revolution in but little less than 19 years. Thus generally we have two solar eclipses in a year, sometimes three or four. The greatest number of both solar and lunar eclipses, that can take place in a year, is seven. The most usual num-

ber is four; two solar, and two lunar. When seven eclipses take place in a year, a node is three times between the sun and earth.

98. The diameters of the sun and moon are supposed to be divided into 12 equal parts called *digits*. These bodies are said to have as many digits eclipsed, as there are of those parts involved in darkness.

Among the ancients, eclipses were regarded much in the same light that comets were, as alarming deviations from the established laws of nature, totally unaccountable, and presaging direful calamity to individuals or to the State. In Ferguson's Astronomy, No. 328, is a short list of eclipses and remarkable historical events, which happened about the same time. A few philosophers arose at intervals, who were able to penetrate the cause of those phenomena, and even to predict their return. But these were few, and did little or nothing towards enlightening their countrymen on these subjects. Genius and skill were put in requisition to search out the regions and subjects against which the malevolent effects of a particular eclipse were aimed. Treatises were written to show, that the effects of an eclipse of the sun continued as many years as the eclipse lasted hours; and that of the moon as many months.

A total eclipse of the sun is a very curious and rare spectacle. Clavius observed one at Coimbra, in Portugal, August 21, 1560. He observes, that the obscurity was more striking and sensible than that of night. It was so dark for some time, that he could scarcely see his hand; some of the largest stars made their appearance for a minute or two, and the birds were greatly terrified.

June 16, 1806, a very remarkable total eclipse took place at Boston. The day was clear, and nothing occurred to prevent accurate obvervation of this interesting phenomenon. Several stars were visible; the birds were greatly agitated; a gloom spread over the landscape, and an indescribable sensation of fear or dread pervaded the breasts of those, who gave themselves up to the simple effects of the phenomenon, without having their attention diverted by efforts of observation. The first gleam of light, contrasted with the previous darkness, seemed like the usual meridian day, and gave indescribable life and joy to the whole creation. It is to be doubted if there was a single person gazing at the sun, or rather the moon, at that moment, who did not feel relieved from an uneasy sensation, and betray that relief in the instantaneous subsequent cheerfulness of his countenance. A total eclipse of the sun can last but little more than three minutes. An annular eclipse of the sun is still more rare than a total one.

SECT. II.

Of Phenomena arising from the Revolution of the Earth on its own axis.

DAY AND NIGHT.

99. Common experience shows, that when we are moving swiftly in one direction, surrounding objects appear to be moving in the opposite direction. This effect is no where more striking than in sailing near a shore or coast. It is difficult for a person in this situation for the first time, to realize that himself, and not the land, is in motion. So by the earth's motion on its axis from west to east, the sun and stars appear to move from east to west. The sun constantly shines upon one half the earth's surface; and by the regular motion of the earth on its axis, every place is successively brought into light and immersed in darkness. This occasions alternate day and night.

100. If the line *NS* (Pl. IV, fig. 4,) about which the earth turns, were always in the circle dividing the light from the dark hemisphere, the days would every where be of the same length, and just as long as the nights. For an inhabitant at the equator, at *o*, and one on the same meridian towards the poles, as at *I*, would come into the light at the same time, would come to the meridian *r Q*, at the same time, and, on the other side, would immerge into darkness at the same time. And since the motion of the earth is uniform, they would be in the dark hemisphere just as long as in the light; that is, the night would be just as long as the day.

101. But this is not the position of the line *NS*, except when the sun is in the celestial equator. But as the ecliptic and the equator make an angle with each other of 23½°, the sun cannot be in the celestial equator, except at the points where the equator cuts the

ecliptic, which are the beginning of the signs *Aries* and *Libra*. The sun enters these signs on the 20th March and 23d of September. Hence at these periods, and at no others, the days and nights are equal all over the world; and on this account they are called *equinoxes*; the first the *vernal* equinox, the second the *autumnal*. At these seasons, the sun rises exactly in the east at 6 o'clock, and sets exactly in the west at 6 o'clock.

102. But at other seasons, when the sun is not in the celestial equator, the line *NS* is not in the circle dividing the light from the dark hemisphere; but has more or less of the position as represented at sign *Cancer* (♋) or *Capricorn* (♑). (Pl. V, fig. 1.) Here it is plain that an inhabitant at the equator *o*, does not come out of the dark hemisphere, or immerge into it, at the same time with an inhabitant on the same meridian towards the poles as at *I*. But while the earth is at ♑, an inhabitant at *I* is in the light hemisphere longer than in the dark; that is, the day is longer than the night. But at ♋, an inhabitant at *I* is in the dark hemisphere longer than in the light. Whereas in all situations of the earth, day and night are equal at the equator.

103. It is plain from these figures, that when the days are longest in north latitude, they are shortest in south latitude, and *vice versa*. It is also plain, that as the sun has declination from the celestial equator either north or south, he shines over or beyond one pole, and not to the other. So that there is a region about one pole, which is a long time in the light hemisphere; and a region about the other pole, which for an equal length of time is in the dark hemisphere. At the poles, there is but one day and one night in a year, each of six months. The distance to which the sun shines beyond the poles is always equal to his own declination; and as his declination can be but 23½°, he can never shine but 23½° beyond a pole. Less circles surrounding the earth at

the distance of 23½° from the poles are called *polar* circles. Less circles surrounding the earth at the distance of 23½° from the equator are called *tropics;* the one on the north side, the *tropic of Cancer;* the one on the south side, the *tropic of Capricorn.*

These terms are indiscriminately applied to these circles, as drawn on the earth, or in the heavens. The subject will show which are meant.

104. When the sun enters the signs ♋ and ♑, (which takes place June 21, and December 22) he is at his greatest declination, and in the tropics. At the first period, which is called the *summer solstice,* days are longest and nights shortest in north latitude; and nights longest and days shortest in south latitude. At the latter period, which is called the *winter solstice,* directly the reverse is the case in each latitude.

105. During a year the earth turns on its axis once more than we have days. The reason of this is, that on account of the earth's motion in her orbit, she turns a little more than once on her axis between the time of noon one day, and noon the next day. For, (Pl. V, fig. 2,) if the earth be supposed at *A* on any particular day, and the place *e* be under the sun at noon, it is manifest that on the next day, when the earth comes to *B*, the place *e* will not be under the sun, when it has completed its revolution; but the earth must revolve through the space *e o*, before it is noon at *e*. So again on the next day, when the earth is at *C*, the earth must more than complete a second revolution by the space *e o*, before it is noon at *e*. These little excesses amount to a whole revolution of the earth on its axis in the course of a year. A complete revolution of the earth on its axis constitutes a *siderial* day; the time from noon to noon constitutes a *solar* or *natural* day. Siderial days are all of the same length; but solar days are not.

The mean difference in the length of a siderial and solar day is 3′ 56″. The cause of the different lengths of solar or natural days will be explained, when we treat of *equation of time.*

For precisely the same reason that the earth turns on its axis once more in a year, than there are solar days, the moon must revolve once more round the earth, than it changes or fulls, in the course of a year. For between one change and another, the earth has advanced in her orbit; and consequently the moon must more than complete her revolution before she can be between the sun and earth. The time she occupies in describing her orbit is the time of her *periodical* revolution; and the time between one change and another, or one full moon and another, is the period of her *Synodical* revolution.

SECT. III.

Of Phenomena arising from the Earth's motion round the Sun, together with the obliquity of the Ecliptic.

ART. 1. *Aberration of Light.*

106. It was stated above, (No. 36,) that light is progressive; that it is not transmitted from one body to another instantaneously. It is about sixteen minutes in crossing the earth's orbit; that is, it moves at the rate of about 200,000 miles a second. The earth also moves in its orbit at the rate of about 68,000 miles an hour; that is, nearly 19 miles a second. On account of these two motions, viz. of light and of the earth, we never see any of the heavenly bodies, especially the stars, in precisely the place they occupy, but a little to the eastward of their true places.

107. To illustrate this, (Pl. V, fig. 3,) suppose light falling upon the earth at *a* from a star in the line *a c*. Were the earth stationary at *a*, the star would be seen by the direct ray *c a*, and would appear to be where it actually is. But while the direct ray *c a* is coming to

the earth, the earth has moved from *a* to *b*; consequently, the star will not be seen by the ray *c a*, but by the ray *c b*; and this in the direction *b d*, parallel to *a c*. Hence the star appears at *d*, instead of at *c*. This effect is called the aberration of light, and amounts to about 20″ of a degree.

If the pupil find the preceding illustration difficult to be understood, it may perhaps be rendered more intelligible, if we suppose the line *a c* to be a long tube or telescope, fixed on the earth in the direction represented in the figure. It is obvious that if a star be seen through this tube or telescope, it must be seen at that place exactly to which the tube or telescope points. Let us suppose that a ray of light would come from *c* to the earth in the same time that the earth would move from *a* to *b*. If the ray should enter the tube or telescope in a direction towards *a*, it is obvious that on account of the motion of the telescope, the ray must strike upon its upper side and be lost before it comes to *a*. But if the ray enter at *c*, in the direction towards *b*, then the motion of the telescope will prevent it from striking its under side; for this is continually sliding, as it were, from under the ray, till the ray reaches *b*. But when the ray reaches *b*, the telescope is in the position *b d*, and the eye looking through the telescope must of course see the star at *d*. Now the effect is just the same on the naked eye, as it would be through a telescope.

Art. 2. *The Seasons.*

108. As the earth's orbit is elliptical, the earth must at one season of the year be nearer the sun, than at another. For instance (Pl. I, fig. 1,) the earth is nearer the sun at *A*, than when in the opposite point of its orbit at *C*. And as the heat and light from the sun are greater as the distance is less, it is plain the earth must receive a greater degree when at *A*, than when at *C*. This circumstance would occasion a variation in the temperature of the air, analogous to the seasons, were the sun always in the celestial equator; that is, if the equator coincided with the ecliptic. But the seasons with us, in north latitude, are not in the least de-

gree occasioned by this circumstance. For the earth is nearest to the sun about the time of the winter solstice (22 *December*), and farthest from him about the time of the summer solstice, (21 *June*).

109. But our *seasons are occasioned by the direction in which the sun's rays fall upon us.* When they fall perpendicularly, or nearest so, the season is warmest; and when they fall most obliquely, or in a slanting manner, the season is coldest. For (Pl. IV, fig. 5,) a much smaller portion of *winter rays* fall upon a given surface, as about Boston, than of *summer rays.* The cause of this difference in the obliquity of the sun's rays is the obliquity of the ecliptic.

110. When the sun is in the celestial equator, (Pl. IV, fig. 4,) which is the case at the equinoxes, when he enters the signs Aries (♈) and Libra (♎), and the earth enters ♎ and ♈, the sun's rays fall perpendicularly at the equator, and with equal obliquity in north and south latitude to equal distances from the equator. (Pl. V, fig. 1.) But while the earth moves from ♎ to ♑, and the sun *appears* to move from ♈ to ♋, (which is done between March 20 and June 21,) the sun appears to recede gradually from the equator, and have a north declination. During this period, the sun's rays do not fall perpendicularly at the equator, but at a region north of the equator, and less obliquely in north latitude than in south latitude. Consequently the season is warmer in north latitude than in south. At the summer solstice (June 21) these effects are greatest. From June 21 to September 22, while the sun *appears* to move from ♋ to ♎, he seems to approach the celestial equator, and actually comes to it September 22, when the rays fall with equal obliquity in both latitudes.

111. But while the earth passes from ♈ to ♋, and the sun from ♎ to ♑, the sun's south declination gradually increases; his rays fall perpendicularly on a re-

gion south of the equator, and less obliquely in south latitude than in north. Hence at this period (December 22) it is summer in south latitude, and winter in north. For this situation the sun gradually returns to the equator, where he arrives at the vernal equinox, March 20.

112. It may be seen by the figures, that at the same time that the sun's rays are nearest perpendicular at any place, the days are also longest, whether in north or south latitude. This circumstance contributes much to the warmth of summer and the cold of winter.

113. Since the degree of heat from the sun increases as the earth's distance decreases, and this distance is least when it is summer in south latitude, and greatest when it is summer in north latitude, it follows, that a greater degree of heat is received in summer in south latitude, than in summer in north latitude. From this circumstance, we might be led to suppose, that south latitude is most favourable to vegetation. But to compensate for a less degree of heat, the inhabitants in north latitude have longer summers than those in south latitude. For, by inspecting the figure, as the sun is not in the centre of the ellipse but in a focus, the earth must pass farther in going one half its orbit, than in going the other half. The earth also moves slower as it is farther from the sun. Hence it occupies a longer time in moving through one half its orbit, than through the other. For example, the earth in longer in passing from ♎, through ♑ to ♈, than in passing from ♈, through ♋ to ♎. There are found to be 8 days more between the vernal and autumnal equinoxes, than between the autumnal and vernal; that is, our summers are 8 days longer than in south latitude.

114. Though the sun's rays fall nearest perpendicularly upon us in north latitude, and the days are longest at the summer solstice, (*June* 21,) and most obliquely,

and the days are shortest at the winter solstice, *(December 22,)* yet the former is not the time of the greatest warmth, nor the latter of the greatest cold. For the atmosphere derives heat, by coming in contact with the earth. So that when the earth is warmest, the atmosphere is warmest, and when the earth is coldest, the atmosphere is coldest. But the earth continues to accumulate heat for some time after the sun's rays are most powerful; and, like a heated ball, is not divested of it till after the period when the sun's rays are least powerful. Hence we have the warmest weather in the latter part of July, and in the first of August; and our coldest month is January. For precisely the same reason, our warmest part of the day is about 2 or 3 o'clock in the afternoon.

115. There is a difference between a solar and siderial year. A solar year is the time in which the earth passes from any point in the ecliptic, as the beginning of Aries, to the same point again; which is a little less than a complete revolution, as will be explained when we treat of the *precession of the equinoxes.* A siderial year is the time of performing a complete revolution.

Art. 3. *Equation of Time.*

116. The medium length of a solar or natural day is divided into 24 equal parts, called hours; which parts are measured by correct time-pieces. But, as was stated above (105), these days are not all of the same length. Hence some must consist of more and some of less than 24 hours. When a natural day consists of more than 24 hours, it is plain that it will not be noon by the sun till it is past noon by the clock; in which case the sun is said to be *slow of the clock.* When a natural day consists of less than 24 hours, it is noon

by the sun before it is by the clock; in which case the sun is said to be *fast of the clock.* Time measured by a clock is called *mean* time; that indicated by the sun, or shadow on a common dial, is called *apparent* time; and the difference between them is the *equation.*

117. There are two causes of the inequality of natural days. The first is, that *the earth's orbit is not a circle, but an ellipse.* It was ascertained by Kepler, that if a line were drawn from the sun to the earth, this line would, by the earth's motion, pass over equal spaces, or *areas,* in equal times. If then the distance of the earth from the sun were always the same; that is, if its orbit were a circle, the earth would pass through equal portions of it in equal times. But as the earth's distance from the sun is constantly changing; that is, its orbit is an ellipse, the earth must pass through unequal portions of its orbit in equal times. That is, it passes through greater portions in some days than in others.

118. To illustrate this, (Pl. VI, fig. 1,) let the plane of the earth's orbit be divided into 12 equal areas, by drawing lines from the sun to 1, 2, 3, 4, &c. In order that a line drawn from the sun to the earth may pass over equal areas in equal times, the earth must pass in her orbit from one of these lines, 1, 2, 3, 4, &c. to another in equal times, that is, in a month, reckoning 12 months to a year. But it is manifest that the portions of the orbit between these lines are unequal. For example, the distance from 1 to 2 is greater than from 6 to 7. Hence the earth must pass through a greater portion of its orbit in one month than in another; and consequently, through more in some days than in others.

119. It was stated, (No. 105,) than in a natural or solar day, the earth turned a little more than once on its axis; and this takes place *because the earth has advanced in its orbit.* Hence as the earth advances in its

orbit farther in one day than in another, the earth must turn on its axis farther in one day than in another; that is, some days are longer than others. (Pl. V, fig. 2,) if the earth in one part of its orbit move from *A* to *B* in a day, the excess over a complete rotation on its axis, in the same time, is *e o*. But if the earth in another part of its orbit should move through a distance equal to *AC*, the excess here would be *e o*, greater than *e o* in the other case. So far as this cause operates, the sun will agree with the clock only at the earth's perihelion and aphelion; that is, a little after the times of the solstices.

120. The second cause of the inequality of natural days, is *the obliquity of the ecliptic.* If the sun moved uniformly in the celestial equator, it is plain that equal portions of the earth's equator and all parallels of latitude would pass under the sun's meridian in equal times; that is, 15° every hour. But the sun's *apparent* motion is not in the celestial equator, but in the ecliptic; and equal portions of the ecliptic do not correspond with similar portions of the celestial equator. Consequently, the sun *appears* sometimes farther eastward, sometimes farther westward, than it would, were it in the celestial equator; and the earth must turn on its axis farther on some days than on others, to bring the same place under the sun's meridian.

121. To illustrate this, (Pl. VI, fig. 2,) let ♈ *N* ♎ *S* be the concave heavens, in the centre of which is the earth. Let the line ♈ ♎ be the celestial equator, and ♈ *a b* ♋, &c. be the ecliptic. Let ♈ 1, 1 2, 2 3, *&c.* be equal distances on the celestial equator, and ♈ *a*, *a b*, *b* ♋, &c. be equal portions of the ecliptic, corresponding to ♈ 1, 1 2, &c. If a star be supposed to start from ♈ with the sun, and move round the earth in the celestial equator, in the same time that the sun *appears* to in the ecliptic, it is plain that the star would pass through

just as many degrees in a given time as the sun would; and would arrive at the points 1, 2, 3, &c. at exactly the same time that the sun does at the points *a b*, ♋ &c. When the sun and star are both together at ♈, they are in the same meridian; but when the star comes to 1, and the sun to *a*, they are not in the same meridian, but the sun is westward of the star's meridian; consequently as the earth turns on its axis from west to east, any particular place will come under the sun's meridian sooner than under the star's meridian; that is, it is noon by the sun before it is by the star or *by a clock*. (For were the sun where the star is, the sun would agree with the clock.) The case is the same while the sun is between ♈ and ♋, and the star between ♈ and 3; that is, during one quarter of the year.

122. When the sun comes to ♋, and the star to 3, they are again on the same meridian, and time is the same as indicated by either. But while they are moving from ♋ and 3 to ♈, the sun's meridian is to the eastward of the star's meridian. Consequently, places on the earth's surface come under the sun's meridian later or after they come to that of the star; that is, it is noon by the sun later than by the clock. At ♎ they again come into the same meridian. While passing through the remaining half of the celestial equator and ecliptic, precisely the same takes place; that is, it is noon by the sun sooner than by the clock in the first part, and later in the last.

123. From this cause of inequality in solar days, it is obvious that the sun and clock would agree only four times in a year, viz. at the equinoxes and solstices; also, that during the first and third quarters, from the equinoxes to the solstices, the sun would be fast of the clock; during the second and fourth quarters, from the solstices to the equinoxes, the sun would be slow of the clock.

124. But the two causes of which we have spoken, counteract each other's effects in such a manner, that the sun and clock do not agree at any period when they would by the operation of either cause singly. They are together only when the swiftness or slowness of equation, resulting from one cause, just balances the slowness or swiftness arising from the other. This is the case four times in a year, viz. about the 15th April, 15th June, 31st August, and 24th December. The greatest possible difference between mean and apparent time is 16¼ minutes, which happens about the first of November, when the sun is fast of the clock.

TABLE

Showing the Equation of Time within a minute, being calculated for the second year after leap year.

Months.	Days.	Equation in Minutes	Months.	Days.	Equation in Minutes.	Months.	Days.	Equation in Minutes.	Months.	Days.	Equation in Minutes.
Jan.	1	4+	Apr.	1	4+	Aug.	9	5+	Oct.	27	16—
	3	5		4	3		15	4	Nov.	15	15
	5	6		7	2		20	3		20	14
	7	7		11	1		24	2		24	13
	9	8		15	0		28	1		27	12
	12	9		*			31	0		30	11
	15	10		19	1—		*		Dec.	2	10
	18	11		24	2	Sept.	3	1—		5	9
	21	12		30	3		6	2		7	8
	25	13	May	13	4		9	3		9	7
	31	14		29	3		12	4		11	6
Feb.	10	15	June	5	2		15	5		13	5
	21	14		10	1		18	6		16	4
	27	13		15	0		21	7		18	3
Mar.	4	12		*			24	8		20	2
	8	11		20	1+		27	9		22	1
	12	10		25	2		30	10		24	0
	15	9		29	3	Oct.	3	11		*	
	19	8	July	5	4		6	12		26	1+
	22	7		11	5		10	13		28	2
	25	6		28	6		14	14		30	3
	28	5					19	15			

Those columns that are marked +, show that the clock or watch is faster than the sun; and those marked —, that it is slower.

ART. 4. *Of the Harvest Moon.*

125. If the moon revolved round the earth in 24 days, it is manifest that its mean daily motion would be (360÷24) 15°, corresponding exactly to one hour of time, consequently the mean daily difference in the time of the moon's rising would be one hour. But the moon is 29½ days in passing from change to change; consequently her mean daily motion is (360÷29½) 12° 12′ 12″, and of course the mean difference in the times of her rising is something less than an hour. It is about 49 minutes. But it was noticed by the husbandman long before astronomers could account for it, that for 6 or 8 nights, near the full moons of September and October, the moon rose nearly when the sun set, and afforded convenient light to continue his occupation. From the peculiar advantages derived from these full moons, the first was called the *harvest* moon, the second the *hunter's* moon.

126. In illustrating these phenomena, for the present let us suppose the moon's orbit to lie in the plane of the ecliptic. Let Pl. VI, fig. 3, represent a common globe rectified for Boston; that is, having Boston exactly at the top, and the circle on which is the word EAST, in the horizon. By turning the globe on its axis *NS*, the *equator* is always at the same angle with the horizon, and equal portions of it come above the horizon in the east in equal times. But not so of the ecliptic. For when the point *Aries* is in the horizon in the east, the preceding sign *Pisces* lies very obliquely to the horizon, and forms but a small angle with it. But when the point *Libra* is in the horizon in the east, the preceding sign *Virgo* is nearly perpendicular to the horizon. From these different angles formed with the horizon by different parts of the ecliptic, it is manifest, that a greater portion of the ecliptic comes above the horizon in a

given time (as 1 hour) when *Aries* is in the east, than when *Libra* is in the east. Suppose while the moon is moving in *Pisces* near *Aries*, it passes from 1 to 2, from 2 to 3, &c. daily. Suppose while moving near *Libra*, it passes from *a* to *b*, from *b* to *c*, &c. daily. By turning the globe, the points 1, 2, 3, &c. come above the horizon very nearly at once; whereas the points *a b*, *c*, &c. come above the horizon in succession at considerable intervals. Hence when the moon is on successive days in the points 1, 2, 3, &c. the difference in the times of her rising is very small; but while successively in the points *a*, *b*, *c*, &c. the difference in the times of rising is very great.

This subject may be illustrated much more clearly by a globe than by any representation on paper. By pasting small black patches on the points 1, 2, 3, &c. and on *a*, *b*, *c*, &c. at the distance of 12° 12' from each other, and by then turning the globe, a clear illustration will be effected.

127. Although the differences in the time of the moon's rising are always great when she is in or near *Libra*, and always small when in or near *Aries*, that is in every moon, yet we do not notice those variations except in autumn. (In fact we seldom notice the moon's rising at all unless it be when she rises near sunset, or in the evening.) The reason is that the moon can be full in or near *Aries*, where the difference in the times of her rising is least, only when the sun is in or near *Libra*; that is, at or near the time of the autumnal equinox.

128. It is plain from the figure, that as latitude increases northward, the difference in the times of the moon's rising in or near *Aries*, decreases. For the part of the ecliptic, *Pisces*, &c. makes a less angle with the horizon. Beyond the polar circle, the moon is above the horizon during half its revolution, as the sun is during half the year. And here is obviously a wonderful

accommodation to the wants of the inhabitants. For when the sun is above the horizon, the moon, being in the opposite part of the ecliptic, fulls below the horizon. And when the sun is below the horizon, and the moon's light most needed, the moon fulls above the horizon; and at the winter solstice, the moon is visible during her second and third quarters when her light is greatest, and is below the horizon only when she reflects but little light.

129. All these appearances take place in south latitude as well as in north, only at a different season. The difference in the times of the moon's rising is there least when the moon is in or near *Libra;* hence their *harvest* moon comes when the sun is in or near *Aries,* that is, in our spring. But our spring is their autumn; so that they derive the same advantages from them, and in the same season, that we do.

130. The effects, as we have stated, take place on the supposition that the moon's orbit lies in the ecliptic. But it does not, but varies from it 5° 20′. This variation sometimes augments and sometimes diminishes the effects, of which we have spoken. When the moon's ascending node is in or near *Aries,* the effects are increased, and the harvest moons are most beneficial; but when the moon's descending node is in or near *Aries,* the effects are diminished and the harvest moons are least beneficial.

The following Table shows in what years the harvest moons are most or least beneficial, from the year 1817 *to* 1861. *The columns of years under* M *are those in which the harvest moon is most beneficial; those under* L *are the years when it is least beneficial.*

M	L	M	L	M
1817	1826	1835	1844	1853
1818	1827	1836	1845	1854
1819	1828	1837	1846	1855
1820	1829	1838	1847	1856
1821	1830	1839	1848	1857
1822	1831	1840	1849	1858
1823	1832	1841	1850	1859
1824	1833	1842	1851	1860
1825	1834	1843	1852	1861

SECT. IV.

Of Phenomena arising from the Earth's Atmosphere.

131. It is found by experiment, that when a ray of light passes obliquely from one medium into another of different *density*, as from air into water, or from water into air, it is bent out of a straight course, and it is said to be *refracted*. For example, (Pl. VI. fig. 4,) if a ray from the sun through the air fall obliquely upon water, or any transparent fluid, at *F*, instead of continuing in that direction to *o*, it will be bent downwards to *Q*; so that if a diver should place his eye at *Q*, he would see the sun at *s* instead of *S*. *The degree of refraction, that is, the distance between* s *and* S, *is greater as the fluid is more dense; and also as the ray falls upon it more obliquely.*

132. A very familiar experiment will illustrate this subject. Put a small piece of money in the bottom of a bowl, (Pl. VII, fig. 1;) let a person fix his eye at *A*, so that he cannot see the money, but a spot a little above it, as *B*. If water be poured into the bowl carefully, so as not to stir the coin, presently it will *appear* to be at *B*, and become visible to the eye at *A*. Had the bowl a glass bottom, another person might look up through the water, and see the eye of the other at *a*. The reason of this appearance is that the light passing from the money through the water into the air, is refracted just as much, as when passing from the air into the water, only *in a different direction*.

133. From what has been stated, it is manifest that if a ray of light pass through several media, as *A*, *B*, *C*, *D*, (Pl. VII, fig. 2,) of different densities, increasing downward, it will be refracted more and more, as it passes from one medium into another; like the lines *ab*, *bc*, *cd*, *de*. Also if *ABCD* be one medium, *uniformly* increasing in density downward, a ray of light, instead of describing the lines *ab*, *bc*, &c. would proceed in a curve line like *fg*.

134. Now the earth's atmosphere is such a medium. Its density is greatest at the surface of the earth, and decreases uniformly upward, till the atmosphere to appearance vanishes at the height of about 45 miles. Hence all rays of light, which enter the atmosphere *obliquely*, come to us in curve lines. But we always see objects in the direction in which the light meets the eye. Hence an obvious effect of refraction by the earth's atmosphere is, that *we never see any heavenly body in its true place, unless it be in the zenith*, where its rays do not fall obliquely on the atmosphere. The sun, moon, and planets can never be in the zenith of Boston; hence we can never see any of them where they actually are.

135. Refraction makes a heavenly body appear to be higher above the horizon, than it really is. To illustrate this (Pl. VII, fig. 3) let *H o* be the sensible horizon to a person at *D*. When a star is at *a*, it will, on account of refraction, appear, to a person at *D*, at *b*. So when the sun is actually below the horizon, at *T*, and consequently not risen, it appears above the horizon at *S*. In like manner when it sets. Hence we see the sun and moon longer than they are really above the horizon. From this cause arose the singular phenomenon recorded in history, that the moon totally eclipsed was visible in the east while the sun was visible above the horizon in the west. It has been ascertained that the sun is visible on account of refraction about 3 minutes before he rises, and about the same time after he sets on a medium through the year. Six minutes are thus added to the length of the day; making in the course of a year about a day and a half. This effect is increased towards the poles.

136. But we have light less or more faint, some time before and after the sun is visible. This is caused partly by refraction, but principally by reflection, of the sun's rays by the atmosphere. This faint light before sunrise and after sunset, is called *twilight*. It commences in the morning and ends in the evening, when the sun is 18° below the horizon. But the sun's apparent daily course is more oblique to the horizon at some places than at others; and at one season of the year, more than at another, at the same place. Hence there is great difference in the times occupied by the sun in passing through these 18°. As the latitude is greater, his course is more oblique to the horizon, and the twilight is longer. For example, twilight is longer at Boston than at New Orleans, and shorter than at London. Twilight is also longer in summer than in winter. At Boston the longest twilight is about the

time of the summer solstice, and the shortest near the 1st of March and October; but uniformly shorter in winter than in summer. The first appearance of morning twilight is usually called *dawn* or *day break.*

137. The evening twilight is longer than the morning; principally because the heat of the sun, during the day, raises clouds and vapours, which increase the density of the atmosphere. Were there no atmosphere to reflect and refract the sun's rays, the sky would appear black, except where the sun is; at sun-set we should pass at once from full day light to darkness, (save the little light which the moon and stars afford,) and *vice versa* at sunrise.

138. There are many curious appearances resulting from refraction. From what has been stated, it follows that refraction is greatest when the luminary is in the horizon, and gradually diminishes toward the zenith, where it entirely ceases. When the sun or moon is in the horizon, as the upper side is higher or nearer the zenith than the lower, rays coming from the upper side are less refracted than those coming from the lower. Hence the difference between the *true* and *apparent* place of the lower edge of the sun or moon is greater than of the upper edge; consequently the figure of these luminaries in the horizon is often observed to be oval or elliptical, instead of circular.

139. When the moon is totally eclipsed she is seldom invisible, but appears of a colour somewhat resembling that of tarnished copper. Now since the moon is at such times wholly in the earth's shadow, how is it that she is at all visible? It is generally supposed, and it can scarcely be doubted, that this effect is produced by the refractive power of the earth's atmosphere. The sun's rays, passing through our atmosphere, are bent inwards; so that the earth's shadow at the distance of the moon is not gross darkness. A few refracted rays

fall upon the moon, and being reflected back render her visible to us.

140. Refraction makes not only heavenly bodies, but also objects on earth appear higher than they really are. For example, when we look at objects actually higher than we are, as a mountain or steeple, they appear still higher than they actually are. For the atmosphere being more dense near the earth's surface, where we are, and rarer upwards, where the objects are to which we look, the light coming from those objects passes in curve lines, bending downwards. This effect is not great when the objects are nigh. But if they are at considerable distance, it may amount to several feet. The most striking effect of this kind is witnessed at sea. In thick foggy weather, a vessel at considerable distance is often so elevated and magnified, (or *looms* up, as seamen call it,) that it appears to be very near.

Atmospherical appearances have always been resorted to as indications of the coming weather, with more or less success, according to the variableness of the climate, and the acuteness and experience of observers. General principles there undoubtedly are, by which prognostics may often be made with a great degree of certainty. Baron Humboldt remarks that "under the torrid zone, where the meteorological phenomena follow each other with great regularity, and where the horizontal refractions are more uniform, the prognostics are surer than in the northern regions. A great paleness of the setting sun, a wan colour, an extraordinary disfiguration of its disk are almost unequivocal signs of a tempest; and we can scarcely conceive how the state of the low strata of the atmosphere (indicated by these appearances), can be so intimately connected with meteorological changes, that take place eight or ten hours after the setting of the sun.

"Mariners have carried the physiognomical knowledge of the sky to a much higher state of perfection, than the inhabitants of the fields. Viewing only the ocean, and the sky which seems to repose upon its surface, their attention is continually fixed on the slightest modifications of the atmosphere. Among the great number of meteorological rules, which pilots transmit to each other as a kind of inheritance, there are several that evince great sagacity; and in general, prognostics are less uncertain in the basin of the seas, especially in the equinoctial parts of the ocean, than on the continent, where the configuration of the ground, mountains, and plains, interrupts the regularity of the meteorological phenomena. The influence of the lunations on the duration of tempests; the action exercised by the moon at its rising, during several successive days, on the dissolution of the clouds; the intimate connexion that exists between the descent of marine barometers and the changes of weather; and other similar facts; are scarcely observed, in inland countries comprised in the variable zone, while their reality cannot be denied by those, who have long been in the habit of sailing between the tropics."

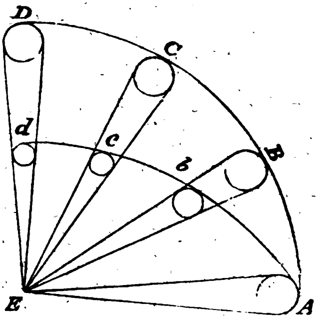
◆

141. Though it properly belongs to the science of optics and not to astronomy, yet it may not be uninteresting to explain here what is called the *horizontal moon.* Every one must have observed that the sun and moon appear bigger in the horizon, than when considerably above it near the zenith. This appearance is supposed to result *entirely* from error in our judgment. *We insensibly consider the horizon at a greater distance from us than the zenith.* Hence the sky above the horizon does not appear to us to form a concave hemisphere, but a figure somewhat like the crystal of a watch.

142. To show how this circumstance accounts for the phenomenon under consideration, we must state, that *in judging of the unknown size of any object, we always first judge of the distance of that object.* For example, in looking at a calf, if I can see all the intervening objects, and rightly estimate its distance to be 100 rods, I shall probably judge rightly of its size, and not mistake it for an ox. But if, by any impediments, I should judge wrongly of its distance, and consider it 500 rods instead of 100, I should undoubtedly judge wrongly of its size, and might mistake it for an ox. Universally if two objects of equal size, and at equal distances from us, be judged to be at unequal distances from us, the one which we consider most distant we shall consider largest.

143. Now when the moon is in the horizon, we see intervening objects; but when above the horizon, we do not. Suppose I observe the moon to rise *apparently* by the side of the trunk of a tree, which I well know to be 200 or 300 rods distant; and which I also well know is nearly 2 feet in diameter, where it appears in the horizon. I see the moon is beyond that tree, and that its apparent diameter is greater than that of the tree; I hence *insensibly* estimate the diameter of the moon to exceed 2 feet; whereas in the zenith I think it scarce six inches. It is from the same cause that in looking across water, or an extensive marsh, we always think the distance less than it really is; there being few intermediate objects.

These estimates are made for illustration only. Different people form very different estimates of the apparent diameter of the sun and moon.



To render this subject more plain, the annexed figure is introduced. Let us suppose an observer at *E*, while the moon passes from the horizon at *A* through *B* and *C* to the zenith *D*. If the observer considers the moon as passing through a part of a *circle*, and always at the same distance at *B*, *C*, and *D*, the moon will appear to him always of the same size. But if, while the moon passes from *A* through the stations *B*, *C*, and *D*, it *appears to him* that it passes from *A* through the stations *b*, *c*, and *d*, it will appear to him less at *b*, than at *A*, and less at *c* and *d* than at *b*. Now this last is the true appearance of the moon, while she rises from the horizon *A* to the zenith *D* in the *circle ABCD*, she *appears* to us to move in the depressed *curve A b c d*, thus continually becoming nearer. Thus we attribute to her a variation in size, because there *appears* to be a variation in her distance.

SECT. V.

Of Phenomena arising from the Earth's Magnitude.

PARALLAX.

144. None of the heavenly bodies, unless they be in the zenith, appear to have the same place among the stars when seen from the earth's surface, that they would have, if seen from the earth's centre. To a spectator at *G*, (Pl. VII, fig. 4,) the centre of the earth, the moon at *E* would appear among the stars at *I*; but seen from the surface of the earth at *A*, it would appear at *K*. The place *I* is its *true* place, and *K* its *apparent* place; and the difference between them is its *parallax*, *diurnal parallax*, or *horizontal parallax*. As the moon comes above the horizon, say to *D*, its parallax decreases; for here it is *H a*, less than *IK*. And when the moon comes to the zenith at *F*, parallax ceases; for it appears at *Z*, whether seen from *G* or *A*.

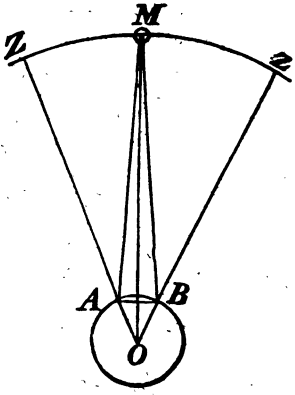
145. *The parallax of a heavenly body is less as its distance is greater.* If the moon were at *e* instead of *E*, its parallax would be *n K* instead of *IK*. The moon's horizontal parallax is about 57′; the sun's 8″. The distance of the stars is so great, that no parallax can be discovered.

146. Refraction and parallax both make bodies appear where they are not; but refraction elevates them, and parallax depresses them. They are both greatest in the horizon, and vanish at the zenith. The moon is depressed by parallax near twice as much as it is elevated by refraction; but the sun is depressed by parallax only about $\frac{1}{250}$ as much as it is elevated by refraction. Refraction is the same, whether the light come from the sun, moon, or any other heavenly body; being generally about 33′ in the horizon.

147. Parallax or diurnal parallax is to be understood as above explained. But there is an *annual* parallax; by which is meant, the difference in the apparent place of a heavenly body, as seen from the earth in opposite points of its orbit. As the mean distance of the earth from the sun is 93 millions of miles, it is obvious that the earth, in one part of its orbit, as at ♋, is (2×93) 186 millions of miles farther eastward, than when in the opposite part, as at ♑. Hence we might suppose, that if a particular star is exactly in the north when the earth is in one part of its orbit, it would deviate somewhat from the north, when the earth comes to the opposite point. (For the earth's axis is always parallel with itself.) But the pole star (and indeed all stars) have no annual parallax, that can be discovered; owing to their inconceivable distance. The nicest instruments which the most ingenious artists have been able to construct, fail entirely to indicate to us any deviation arising from this cause of any star from its true place. But these instruments would indicate such deviation, were not the stars more than 200,000 times farther off than we are from the sun. (18,600,000 millions of miles.) The probability is, that the nearest stars are at a much greater distance.

The following Numbers of this section cannot be fully understood without a knowledge of plane Trigonometry. They may therefore be omitted by those who are ignorant of that branch of mathematics.

148. The distance of the moon was long since ascertained with the utmost accuracy by means of her parallax. There are several methods of obtaining this parallax, and of applying it. The following is one of the most sure and simple. Let us suppose that two observers are at the points *A* and *B* in the same meridian; and let the distance between them, that is, their difference



of latitude, be previously known. When the moon *M* passes the meridian of these observers, let each, with a good instrument, take her *zenith distance;* that is, the arc *ZM* and *zM*. In the triangle *AOB*, the sides *OA* and *OB* are each equal to the semidiameter of the earth, which is known; and the angle *AOB* is measured by the arc *AB*, which is the difference of latitude between the observers, and is also known (by the supposition.) These three things therefore being known, we can readily calculate the length of the side *AB*, and the magnitude of the angles *OAB* and *OBA*.

149. Now the zenith distances *ZM* and *zM*, (which have been observed) measure the angles *ZAM* and *zBM*. If then each of these angles be taken from 180°, we have the angles *OAM* and *OBM*. If from the angle *OAM* we take the angle *OAB*, we get the angle *MAB;* and if from the angle *OBM*, we take the angle *OBA*, we get the angle *MBA*. Here then in the triangle *MAB*, the angles *MAB* and *MBA*, and the side *AB* are known; and hence can be found the side *MB*, which is sufficient for our purpose. Now in the triangle *MBO*, these three things are known, viz. the sides *MB* and *BO*, and the included angle *MBO;* hence may be found the length of the side *MO*, which is the distance of the moon from the earth. In the same way might the distance of other heavenly bodies be found were not their distance so great and the parallax so small that *accurate* observations could not be made.

Proper allowance must here be made for refraction.

150. The ancients, so far as we know, were quite ignorant of the *real* distance of the earth from the sun. The solution of this problem baffled the skill and mocked the toil and industry of astronomers for ages; and it was not till very lately that any certain knowledge was gained on this subject. The first approximation towards the truth was obtained by observing as correctly as possible the precise time when half the moon's visible hemisphere is enlightened. For it will be obvious on a little reflection, that this must be the case when the plane of the circle dividing her dark from her illuminated hemisphere, would pass through the centre of the earth; and this takes place a little before the first quarter and a little after the third quarter. When this is the case, the angle made at the moon by lines drawn to the sun and to the earth, is a right angle. By observing the number of degrees between the moon and sun at this time, the angle made at the earth by lines drawn to the sun and moon is obtained. And the distance of the moon from the earth is already known. Here then is a triangle, of which two angles and one side are known; and hence the other sides may be obtained, one of which is the distance of the earth from the sun.

151. But no observation can be fully relied on for determining the very moment when half the moon's visible hemisphere is enlightened; that is, when the line, dividing the dark from the light portion of the moon's disk, is a straight line. Some other means was therefore to be devised for ascertaining accurately the real distance of the earth from the sun. Dr. Halley in 1691 devised the method of finding this distance by observing a *transit*, (that is, a passing,) of Venus over the sun's disk, hence deducing the sun's parallax. As no transit occurred in his day, he could only call the attention of future astronomers to these phenomena,

when they should occur. A transit took place in 1761, and another in 1769; on both which occasions astronomers went into different parts of the world in order to take observations under a variety of circumstances. But the observations of the latter transit did little more than confirm the result derived from the observation of the former.

152. Before we proceed to show how the parallax of the sun can be obtained from a transit of Venus, it may be useful to state some of the facts and principles respecting the motions and orbits of the planets, which were actually discovered from observation, and most of which were necessary to be known before the sun's parallax could be found.

1st. By observations, astronomers had determined the precise time in which each planet completes its revolution.

2d. Kepler, by comparing observations, developed this law, viz. *The squares of the periodical times of the planets are to each other as the cubes of their distances from the sun.* Hence, since the periodical times are known, the *relative* distances of the planets from the sun are readily found. For example, let the periodical times of Venus and the earth be known, and let us suppose the distance of the earth from the sun to be 10; then say, as the square of the earth's periodical time is to the square of the periodical time of Venus, so is the cube of the earth's supposed distance (10,) to the cube of the distance of Venus (7¼ nearly.) In the same way the relative distance of the other planets may be obtained.

3d. By observation, the relative *angular*[*] motion of Venus and the earth was found; and consequently the

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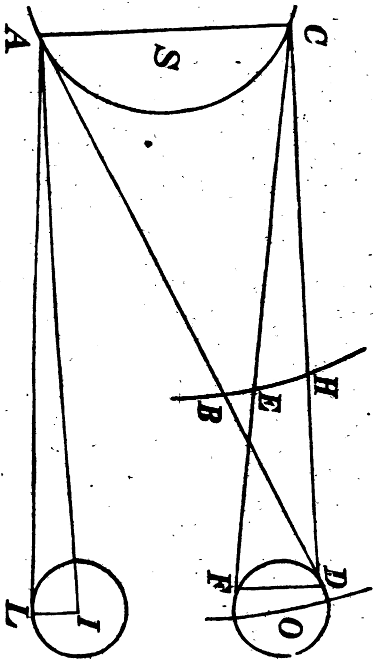
[*] It may be necessary for the instructer to explain to the pupil the difference between *angular* motion and *absolute* motion; that the first is estimated by *degrees*, as seen from the sun, and the second by *miles*.

excess of the *angular* motion of Venus over that of the earth.

4th. Observation had enabled astronomers to determine the position of the orbits of Venus and the earth; so that the part or limb of the sun might be known, over which Venus would appear to pass at any particular transit; and also the direction and duration of the transit, as viewed from the earth's centre.

153. Let us then suppose the duration of the transit to be computed beforehand, as seen from the centre of the earth. Let *S* be the sun, *BEH* part of the orbit of Venus, and *O* the earth in its orbit. For the greater advantage, let the transit be observed from a place, as *D*, where the sun will be on the meridian about the middle of the transit. Let us suppose that Venus at *B* is seen at *D* as entering on the sun's disk at *A*. If the place *D* were stationary with regard to the earth's centre, Venus must move by the excess of her angular motion over that of the earth, from *B* to *H*, before it would appear to



pass off the sun's disk at *C;* the time of doing which, let us suppose to be the same as the calculated duration of the transit as seen from the earth's centre. But during this time, by the rotation of the earth on its axis, the place *D* is carried eastward to *F*, where it is at the end of the transit; so that instead of coming to *H*, Venus moves only to *E* in its orbit before it is seen passing off the sun's disk at *C*, and the transit is ended.

154. Hence it is obvious, that *the duration of the transit*, as computed for the earth's centre, *is shortened* by the motion of the place from *D* to *F*, *by the time it would take Venus to move from* E *to H.* Hence by observing the difference between the computed and observed duration of the transit, we have the time which Venus takes in passing from *E* to *H* by the excess of her angular motion over that of the earth; and since this excess is previously known, by turning this difference of time between the computed and observed duration of the transit into degrees and minutes of that excess, we get the number of degrees and minutes between *E* and *H*, that is, we get the angle *ECH*, or *DCF*. Now the line *DF* may be readily computed from the latitude of the place and the observed duration of the transit; and may be compared with the semidiameter of the earth. From this comparison would be seen at once the angle at *C*, which a semidiameter of the earth would subtend; that is, the sun's parallax. Let this parallax be equal to the angle *IAL*, subtended by the semidiameter of the earth *IL*. Here then we have a triangle *IAL*, of which the angle at *A* is known, and the angle at *I* a right angle, and the side *IL*, equal to the earth's semidiameter, is known; whence may be known the angle at *L*, and the side *AI*, which is the earth's distance from the sun.

155. Having obtained the absolute distance of the earth from the sun, and the relative distances of all the planets being previously known, their absolute distances may be at once ascertained. For, as the *relative* distance of the earth is to its *absolute* distance, so is the *relative* distance of any planet to its *absolute* distance.

In what has been said of the method of finding the parallax of the earth, and thence the distances of the planets from the sun, none of the difficulties of its execution appear. Incredible pains were taken by astronomers in making accurate calculations, and in providing the means for numerous and accurate observations, previous to the transits of 1761 and 1769. The skilful and scientific of Europe were scattered over the habitable globe, for the purpose of observing this phenomenon under circumstances as various as possible. Some went to India, others to America; some to the north of Europe, others to the south. The truth was arrived at by vast labour in comparing an almost endless variety of observations, made at different places; correcting the probable error of one observation by the probable opposite error of another observation, thus taking a mean of the whole. For a more full account, the pupil is referred to Ferguson's Astronomy. There will not be another transit of Venus till the year 1874.

BOOK II.

PHYSICAL ASTRONOMY.

Attraction.

156. There is one property common to every particle of matter in the universe, viz. it tends to every other particle. However near, or however remote from each other, still they all tend to each other, in a greater or less degree. This universal tendency constitutes what is called the principle of *universal gravitation* or *attraction.* If a stone be flung into the air, it comes to the ground. The tendency, which causes it to fall, is *gravitation.* It is precisely the same as weight. When a body is said to weigh a pound, the meaning is, that the tendency of that body to the earth is equal to the tendency of another body, called a pound weight. The unknown tendency or gravity of one body is compared with the known tendency or gravity of another; and as the unknown exceeds or falls short of the known, it is said to weigh more or less than a pound. So of any number of pounds.

157. But this tendency or gravitation is not uniform. It is varied by one and only one circumstance, viz. *distance.* Two particles close together are more strongly attracted towards each other, than if far apart. But this attraction varies according to a certain known law. *It decreases as the square of the distance increases.* For example, if two particles be two inches apart, the attraction is 4 times greater than if four inches apart; for the square of 2 is (2 × 2) 4, and the square of 4 is (4 × 4) 16; and 16 is four times greater than 4. The very fact that attraction or gravitation operates in this manner, proves that it can never entirely cease; for two bodies can never be infinitely distant.

158. When there is no distance between two or more particles, they adhere and form a distinct body; which attracts and is attracted, like a single particle. But as every particle in this body attracts every particle out of it, just as much while they adhere as if they were separate, it follows that one body attracts all others more or less according to the number of particles it contains; that is, *its solid contents.* If a stone be flung into the air, it falls to the earth, because the solid contents of the earth exceed those of the stone. But the earth also is at the same time drawn towards the stone, and actually moves towards it. If the solid contents of the stone and of the earth were equal, that is, if these bodies were equally *heavy,* they would meet half way. If the solid contents of the stone exceeded those of the earth, as much as those of the earth exceed those of the stone, the earth would fall to the stone, just as the stone does to the earth. *Hence all attraction of bodies is mutual; and greater or less, according to their solid contents.*

159. If two unequal bodies be drawn towards each other by mutual attraction, the distances of the points, where they would meet (called the *centre of gravity*) from the points whence they set out, will be inversely as their solid contents. For example, if a body of 40 pounds, and a body of 10 pounds, move to each other in a straight line, the body of 10 pounds will move 4 times faster than that of 40 pounds; so that if the distance be 100 yards, the centre of gravity is 80 yards from the point where the body of 10 pounds set out, and 20 yards from the point where that of 40 pounds set out. Whence it follows, that *if the weight of each body be multiplied into its distance from the centre of gravity, the product is the same.* ($10 \times 80 = 800$, and $40 \times 20 = 800$.) This is universally true, and affords an easy method of finding the centre of gravity of two

bodies. Say, *as the weight of both bodies is to the whole distance between them, so is the weight of one to the distance of the other from the centre of gravity.*

160. But if every particle and body of matter attracts and is attracted by all others, the question is forced upon us, why do they not come together and form one body? Why does not Uranus fall upon Saturn, and both together upon Jupiter; and since the solid contents of the sun very much exceed those of all the planets together, why do they not all leave their orbits and blend with him into a common mass?

161. Besides the tendency, which every body has to all others, there is another circumstance attending inanimate bodies no less universal, viz. *inertness.* For example, a body at rest tends to remain at rest, and requires a force to put it in motion. So a body in motion tends to move in a straight line, and requires a force to turn it out of a straight line. And the swifter the motion is, the greater is the force required to change its direction. If a ball be thrown swiftly among ninepins, it is not easily turned out of a straight course; but if slowly, a slight obstruction gives it a new direction.

162. We have then these two facts relating to bodies: —1st, *they attract each other;* and this *attraction decreases as the square of the distance increases.* If the bodies be unequal, *they attract according to their solid contents.* 2d, *Every body in motion* (as all bodies are) *tends to move in a straight line; and this tendency is greater as the motion is more rapid.* By the application of these principles we account for the phenomena treated of in the following sections.

It is to be noticed, that no *natural* principle accounts for the origin of motion. The origin of motion and of life is the same, GOD. We find ourselves living creatures; we find the bodies of the solar system in motion. Philosophy as readily accounts for one fact as the other. Both are beyond its reach.

SECTION 1.

Of the Motion of Heavenly Bodies in their Orbits.

163. Let *S* be the sun, (Pl. VIII, fig. 1,) and the earth at *A* in motion towards *B*. Suppose this motion such as would carry it to *B* in the time that the sun's attraction would carry it to *C*. Here the earth has two tendencies, one to move in the straight line *AB*, and the other to go to the sun in the direction *ACS*. Which of these courses will the earth take? Obviously neither; but will go in a middle direction and come to *D*, describing the part of a circle *AD*. When at *D*, the earth tends to move in a straight line towards *F*, and is also attracted by the sun towards *E*. Here again it must take a middle course and come to *G*, describing another portion of a circle. In this way the earth would describe successively all the parts of a circle and come again to *A*.

The force which propels a planet in its orbit is called the *projectile* or *centrifugal force;* that which draws it to the centre, the *centripetal force.*

164. This shows how a planet may revolve in a *circular* orbit, but not in an *elliptical;* and the orbits of all the planets are ellipses. If the earth revolved in a *circle*, the power of the sun's attraction would be always the same; for the earth's distance and solid contents would be always the same. But since the earth's orbit is elliptical, its distance from the sun is continually varying, consequently the power or force of the sun's attraction is continually varying. In order therefore to bring the earth back to the point, whence it is supposed to start, its tendency to move in a straight line must also continually vary.

165. To illustrate this, suppose the earth at *A* in

motion towards *B* with a velocity, which would carry it to *B* in the time that the sun would draw it to *c*. It is plain that instead of describing the part of the circle *AD*, it would describe a part of a different orbit *A d*. At *d* it would tend to move in the line *d f*, and the sun would draw it towards *e*; again it would take a middle course, and come to *g*. In this way it would proceed onward to the completion of half its orbit at *q*; and this orbit is elliptical.

166. But it is not plain, why the latter orbit is an ellipse and the former a circle. To explain this, close attention must be given to the direction of the two forces, projectile and centripetal. In the first case, when the earth is supposed to move in the circle *ADC*, these forces act at right angles to each other in whatever point of its orbit the earth may be. And *universally when two forces act at right angles to each other, one does not counteract the other.* For example, the projectile force would carry the earth from *A* to *B* in the time that the sun would draw it to *C*; it comes to *D*. Now the point *D* is as far from the line *ACS*, as *B* is; consequently the projectile force has carried the earth just as far as it would in the same time, if the sun had not attracted it. So the point *D* is as far from the line *AB* as *C* is; consequently the sun has drawn the earth through just the same space which it would, if there had been no projectile force. The same is true in every part of the circular orbit; and these forces are said to *balance* each other.

167. In the second case, when the earth is at *A*, these forces act at right angles; but the projectile carries it to *B*, while the centripetal would bring it only to *c*. Consequently it comes to *d*, and hence to *g*, &c. But when the earth is at *d*, it is plain that the projectile and centripetal forces do not act at right angles; but the sun's attraction tends to draw the earth backward, and to

prevent it from going as far in the second portion of time as it went in the first; the distance *d g* being less than *A d*. This effect becomes more and more apparent, till the earth completes half its orbit at *q*. During this part of the orbit, the projectile force more than balances the sun's attraction. But the sun's attraction is constantly diminishing that force; till at *q*, the sun's attraction more than balances it, and the earth begins to approach the sun. At *q*, these forces act again at right angles; but the projectile force being overbalanced would carry the earth to *o*, while the sun's attraction would bring it to *r*; it consequently comes to *m*. At this point these forces do not act at right angles; but the sun's attraction tends to increase the projectile force. And this effect is more and more obvious till the earth comes to *A* again, and these forces act at right angles. In this manner, the planets, primary and secondary, continually describe elliptical orbits.

168. Since all attraction is mutual, it is obvious that the sun does not remain entirely at rest, while the earth performs its revolution; but must also perform a small revolution round the centre of gravity, which (on account of the smallness of the earth) cannot be far from the sun's centre. In this revolution, it is also manifest that the sun's motion must be very irregular. For while the earth is drawing him one way, some of the other planets are drawing him in an opposite or side direction.

169. In like manner, while the moon performs its revolution round the earth, the earth also describes a similar revolution round the centre of gravity. But as the difference in the solid contents and distance of these two bodies, is no way comparable with that of the sun and earth, the centre of gravity is not very near the earth's centre, but is about 2 000 miles from the earth's surface.

170. But the planets of our solar system are not the only bodies which have orbits. It was stated above, *No.* 50, that many stars, which appear single to the naked eye, appear double, treble, or even quadruple, when seen through a telescope. According to the observations of distinguished astronomers, it has been found that in many cases the stars, composing these double stars, change their situation with regard to each other; and hence it is inferred that they revolve round a common centre of gravity. Dr. Herschel, during a series of observations on double stars, has found that in more than fifty of them, this change of situation really takes place; and that therefore they describe orbits round a centre of gravity. Some of their periodical times he has calculated; but the accuracy of his calculations remains to be tested.

171. Besides these motions of the single stars composing double ones, it is beyond question that many of the other stars have motions peculiar to themselves. An apparent change of place in some of the stars was first discovered by Dr. Halley, by comparing their present places with their places as laid down in ancient catalogues. Other astronomers confirmed his observations, and this motion of the stars is termed their *proper motion.*

172. If the stars be suns and have motion, does our sun also have motion? If so, the whole solar system of planets, primary and secondary, must partake of his motion, and be carried along with him. It will be obvious on a moment's reflection, that if we are moving towards one part of the visible heavens, the stars in that quarter will appear to recede from each other; while those in the opposite part, from which we are moving, will appear to approach each other. Now observation shows that the stars in one region of the heavens do actually appear to recede from each other, while those

in the opposite region appear to draw nearer together. Hence we seem to have evidence little short of demonstration, that the sun and we with him are in a progressive motion. The constellation Hercules is the region, to which this motion appears to be directed.

173. If the stars and the sun have motion, if they describe orbits, around what do they move? Hitherto we have stated only observations and the conclusions resulting from them. But here observation has not been continued for a length of time sufficient to justify even a conjecture. All is speculation. Herschel supposes (and the supposition has simplicity and beauty, and hence probably truth) that the sun is one of an innumerable multitude of stars composing the milky-way; that all these stars with their systems have a motion round a common centre of gravity. But where this centre is, he does not pretend to conjecture. It is also probable that those whitish regions known as *nebulæ*, (of which Dr. Herschel has given a catalogue of 2500,) are each composed of a system of stars describing orbits round a centre of gravity, like the stars of the milky-way. Still the analogy of the universe is not complete without giving these systems of stars, these milky-ways, a progressive motion; without supposing, that they describe each an orbit round a common centre. But here we must stop, for no more materials are given.

SECT. II.

Of the retrograde Motion of the Moon's Nodes.

174. Under the article Eclipses, it was stated, that the moon's nodes were not always in the same points of the ecliptic, but had a motion backward, contrary to the order of the signs; by which motion the line of the nodes

performs a complete revolution in little less than 19 years. It remains to explain the cause of this motion.

175. The moon's orbit cuts the ecliptic at an angle of 5⅓°; that is, the moon departs 5⅓° from the ecliptic, north and south. Let *S* (Pl. VIII, fig. 2,) be the sun, *E* the earth, the line *SE* the plane of the ecliptic, the line *M m* the plane of the moon's orbit, and *M*, *m*, the moon in the two opposite points of her orbit, where she is farthest from the ecliptic. When the moon is at *m*, the sun draws it towards *S*, and the earth towards *E*; these two attractions bring it downwards towards *e*, and make it cut the ecliptic sooner than it would if the sun did not attract it. So when the moon is at *M*, the moon draws the earth to itself, and the sun to himself; these two attractions tend to bring the earth towards *r*. But as the earth is much larger than the moon, it is carried but little way towards *r*; but the moon is carried in the other direction towards *x*, so that it cuts the ecliptic sooner, than if attracted by the earth only. To make this plainer, fig. 3 and 4 are different views of parts of the ecliptic and of the moon's orbit. *EC* is a part of the ecliptic, *EM* a part of the moon's orbit, *M* the moon, *E* a node. The joint action of the sun and earth brings the moon, not to the node *E*, but along the dotted line to *r*.

SECT. III.

Of Irregular Motions.

176. Since attraction is *mutual* and *varies according to the distance of the bodies*, it is obvious that in a system of bodies moving round a common centre in different times, there must be irregular motions. For example, since the earth and Jupiter move round the

sun in different times, they will be nearer to each other at one time than at another; and consequently will attract each other more powerfully at one time than at another. This more powerful attraction must draw these planets more or less out of their regular orbits, and thus disturb each other's motion. So also of all the planets. But it is not very difficult to calculate the principal disturbing forces of the planets on each other's orbits and motions.

177. It was remarked at the close of *Sect.* 7, (*Chap.* I. *Book* I,) that some irregularities in the motion of the old planets induced astronomers to suppose that a planet existed between Mars and Jupiter, long before the small new planets were discovered. Some disturbances and deviations in the motions of Jupiter and Saturn were also observed by astronomers before the discovery of Uranus, which they could account for only by supposing them caused by a planet, still more distant from the sun than Saturn. It is obvious, that three immense bodies, like Jupiter, Saturn, and Uranus, revolving at inconceivable distances from the centre, must be very perceptibly disturbed by the variation of each other's attraction; since they are some times three or four times nearer each other, than at others.

178. The moon being a small body, its motions are greatly disturbed and become very irregular on account of the unequal attractions, to which she is exposed. Lying always, more than any other heavenly body, under our observation; and for the purpose of calculating eclipses and for finding longitude, it being very important for us to know her true place; astronomers have taken incredible pains to detect and calculate the effects of the forces, which disturb her motion. So that now, to find her true place to a great degree of accuracy, nearly fifty corrections of her mean motion become necessary.

179. In revolving round the earth, the moon is sometimes nearer the sun than the earth is; and sometimes farther off than the earth is; and is therefore disturbed by the varying attraction of the sun. For example, (Pl. II, fig. 3,) when the moon is in or near *F*, the attraction of the sun will make her move faster than she would if attracted by the earth only; because the direction of the sun's attraction coincides more or less with the direction of the moon's projectile force; and also because she is nearer the sun and more attracted by him than the earth is. The moon being thus accelerated from *F* to *A*, continues to move with something more than her mean velocity, till she comes to *B*; where it is found, that she is little more than her own diameter forward in her orbit, farther than she would have been had she been attracted by the earth only. But while moving from *B* through *C*, the sun's attraction tends to draw her backward in her orbit, and retards her motion just as much as it was accelerated before; so that when she comes to *D*, she is as much too slow in her orbit, as she was too fast at *B*. While moving from *D* through *E*, she is less attracted by the sun than the earth is; this produces the same effect as was produced in the opposite point of her orbit at *F*, *viz.* acceleration of her motion. Thus, when she comes to *I*, she is again too fast; and when at *F* she is too slow. (*When the moon is at B, D, I, & F, she is said to be in her* 1*st*, 2*d*, 3*d*, *&* 4*th* OCTANT; *when at A, or at E, she is said to be in* SYZYGY.) Hence it appears, that the moon is too fast in her orbit in the 1st & 3d octant, and too show in the 2d & 4th. Also that the moon's motion is greater than her mean motion in syzygy, and less than her mean motion in quadrature; and that she moves at her mean rate only in the octants.

180. The disturbing force of the sun, on the moon's

orbit and velocity, is obviously greater as the distance of the earth from the sun is less. Now the earth is nearer the sun in winter than in summer; hence the disturbing force of the sun on the moon is greater in winter than in summer. The consequence is, in winter, when the moon is at *A*, she is drawn away from the earth farther than in summer; and when at *E*, the earth is drawn away from the moon more than in summer. The effect is, that the distance between the moon and earth is greater in winter than in summer; and hence the moon occupies a longer period in completing her revolution in the former season, than in the latter. The difference is about 24 minutes.

181. It is recorded in history, that an eclipse of the moon took place at Alexandria on the 22d Sept. 201 years before the Christian era, and that when the moon arose, she was so much eclipsed, that the eclipse must have begun half an hour before she rose. But according to our Tables, this eclipse did not begin till ten minutes after the moon rose at Alexandria. Now had this eclipse begun and ended while the sun was below the horizon, it might have been supposed that the observer, who had no certain way of measuring time, might have been so far mistaken in the hours, that we could not rely on the accuracy of his account. But as in the case given, the sun had not set and the moon had not risen, till some time after the eclipse began; this circumstance is such, that the observer could not be mistaken in it.

182. From this, and many other instances of discordance between ancient records and our own Tables, it is certain that the moon now describes a less orbit, and occupies less time in a revolution, than she did formerly. This fact led astronomers, and Ferguson among them, to suppose that the moon met with some resistance in her orbit, so that her projectile force was

continually diminished, and her centripetal force increased. They hence inferred that the moon would continually draw nearer and nearer to the earth by slow degrees, till at length they would fall together.

(See Ferguson's Astronomy, Nos. 163 *and* 322.*)*

183. But by examining the effects of the several planets, and especially of Jupiter and Saturn, on the form of the earth's orbit, La Place, an eminent French astronomer, has discovered that the eccentricity of the earth's orbit has been diminishing from ancient time; and that this diminution is the cause of the acceleration of the moon's motion, which we are now considering. The subject is too intricate to admit a familiar illustration; but it is important, as putting to rest all those fears of an ultimate wreck of this world, which were grounded on the *apparently* inevitable effects resulting from the principle of gravitation. La Place also discovered that this, and all other irregularities in the Solar System, generated by the mutual action of the planets, are all periodical, confined to narrow limits, and balanced by irregularities of an equal and opposite kind. After reaching a certain limit, they gradually diminish, till the system, regaining its balance, returns to that state of harmony and order, which preceded the commencement of these secular inequalities.

184. But there is no class of bodies liable to so great disturbances as comets. The same comet is sometimes twice as far distant from the sun as Uranus, and in a different part of its orbit, twice as near to him as we are. Hence the motion of these bodies is very variable. They cross the orbits of the planets in all directions; and are of course accelerated, retarded, and turned out of their course, according as they actually approach these bodies. Dr. Halley computed that the disturbing power of Jupiter alone on the comet of 1682, would retard its return 511 days; and Clairaut

computed that that of Saturn would retard it 100 days; making together nearly a year and three quarters. And the event proved that these computations were very accurate.

185. Though comets are sensibly disturbed by the planets, we have not the same evidence, that the planets are ever sensibly disturbed by them; probably owing to their being generally very small and rare bodies, consisting of very little solid substance. In 1454, the moon is said to have been eclipsed by a comet, which therefore must have been very near both to the moon and earth. Yet it produced no sensible effect on either of these bodies; there being no perceptible deviation from their accustomed path round the sun. The comet of 1770 came so near the earth, that La Place computed, that its periodical time would be increased by the disturbing action of the earth something more than two days; and if its solid contents had equalled those of the earth, it was calculated that it would have retarded the earth's motion in her orbit, and thereby have lengthened our year, 2 hours and 48 minutes. It is certain that no such increase took place; and therefore the disturbing force of the comet on the earth was insensible. The same comet passed through the midst of Jupiter's satellites.

We have stated that in ancient times comets were looked upon with terror as harbingers of evil. Their appearance and disappearance were phenomena totally unaccountable. But when Newton had developed the laws of their motion, and had assigned them their true place in the Solar System, the superstitious fear of the ancients gave way to the philosophical fear of the moderns; a fear, which (for all that we can see) must ever harass the mind, which is not disposed to acknowledge a Supporter and Governor of the universe as well as a Maker of it. When it was ascertained, that a great number (none can tell how many) of these bodies were continually moving in all directions through the different regions of our planetary system, it was apprehended that some of them might meet the earth in its course, and thereby produce a shock,

which might be nearly or quite destructive to the human race. Imagination was let loose; and most of the great physical evils, which our race are said to have suffered, and the most direful which they can look forward to, have been traced with ingenuity to comets. So that long after the law of their motions was well known and understood, the appearance of a comet excited juster (because more definite) fear in the breast of the philosopher, than in the ancient peasant. Nor is this fear yet removed. Astronomers, it is true, have calculated the *chances* of collision between the earth and a comet, and have found the chance greatly against such an event. But according to their calculation, there is a *chance* of such an event; and while this is admitted, there must be fear that it will take place. This fear probably pervades most people more or less; and while we are confined to philosophy, and philosophy developes no new laws of motion, it is unavoidable, and can be resisted and overcome only by a full belief, that there is a Divine Providence overruling and directing all, even the most minute operations, which are exhibited to us in the natural world. There can be no occasion for fear of any effects resulting from operations, which we acknowledge to be directed and governed by divine wisdom, which sees the end from the beginning; and the design of which, we feel assured, is the welfare and happiness of man.

SECT. IV.

Of the Spheroidal Figure of the Earth and other Planets.

186. It has been stated, that as a body moves faster, its tendency to move in a straight line is greater. Now if two bodies describe unequal circles in the same time, as in one day, the body which describes the largest circle must manifestly move faster, than the body which describes the least; consequently, its continual tendency to move in a straight line is greater than that of the other. For example, (Pl. IX, fig. 3,) if a body at *A* describe the circle *A a*, in the same time that a body at *B* does the circle *B b*, the body at *A* must obviously move faster than that at *B*; and consequently

it tends, in every part of the circle, to move in a straight line more than that at B does.

187. Now the parallels of latitude (Pl. II, fig. 1,) on the globe, are circles of different lengths. The equator is the greatest circle, and parallels diminish towards the poles. Hence those bodies, which lie on or near the equator, are carried by the earth's rotation on its axis through larger circles in a day, than bodies lying near the poles. Whence it follows, that bodies near the equator have a greater tendency to move in straight lines, and *consequently to recede farther from the earth's centre*, than bodies near the poles; while at the poles this tendency entirely ceases.

188. Were the earth composed of a liquid, as water, it is hence plain what would be its form. By rotation on its axis, the parts about the equator would swell outward, while the regions about the poles would be somewhat depressed and flattened. It would take something of the form of a flat turnip, or of two saucers put together. Now, though the earth be not a fluid, yet it is not a perfectly solid mass. Its parts are not very difficult of separation. By daily rotation it has actually taken something of the form, which it would take were it a fluid. Its diameter through the equator is greater than through the poles by about 26 miles. As most, if not all the heavenly bodies turn on an axis, most, if not all, partake of the same form as the earth.

189. There is one striking fact resulting from this figure of the earth. Pendulums vibrate by the force of gravity. When propelled sideways, gravity carries a pendulum back; and in carrying it back, gives it such velocity as to carry it as far on the other side; whence it returns, and is again carried to the other side, and so on. As these vibrations are continued by the force of gravity, they must be quicker as the force of gravity is increased. For any body, propelled by a greater force,

must move quicker than when propelled by a less. Now all bodies on the earth's surface are drawn to its centre; and more powerfully, as the square of their distance is less. Hence, if one portion of the earth's surface be farther from its centre than another, the force of gravity on a pendulum in one place must be less than in another; and consequently the pendulum will vibrate slower in one place than in another. This is found to be actually the case. Pendulums vibrate faster towards the poles, and slowest at the equator. This effect is considerably augmented by the centrifugal force of the body being increased as it approaches the equator. For the same reasons, bodies are heavier at the poles than at the equator.

Pendulums of the same length vibrate in the same time, however different in weight. Short pendulums vibrate quicker than long ones. Pendulums vibrating seconds at London, are 39.2 inches in length; but at the equator 39.1 inch nearly.

TABLE

Showing the proportion of the Polar to the Equatorial Diameters of the Planets; as far as known.

Earth	326	to	327
Mars	15	"	16
Jupiter	12½	"	13½
Saturn	32	"	35

SECT. V.

Of the Precession of the Equinoxes.

190. It has been stated that there is a difference between a solar and siderial year. A *solar year* is measured from the time the earth sets out from a particular point in the ecliptic, as an equinox or solstice, till it returns to the same point again. This is found to take

place before it completes its revolution, *which is a siderial year*. For example, (Pl. IX, fig. 1,) if the sun *S*, earth *E*, and a star be in the same straight line at an equinox, the earth revolving through *a*, will not be at *E* at the same equinox, but somewhere at *e*. Hence it must revolve farther, from *e* to *E*, before it completes its revolution; and the time of doing this is the difference between a solar and siderial year, and amounts to about 20 minutes. The distance *e E* is about 50″ of a degree annually, and constitutes what is called the *precession of the equinoxes*.

191. The precession of the equinoxes is to be accounted for in much the same way that the retrograde motion of the moon's nodes is. It has been stated, that the diameter of the earth at the equator is greater than through the poles. Suppose this excess of matter about the equator to be a ring round the earth, but separate from it, leaving the earth a perfect globe or sphere. Let *A b B c* (Pl. IX, fig. 2,) be a circle in the plane of the ecliptic. Let *ACB* be half the ring we have supposed, lying above the ecliptic, and making an angle with it of 23½°. Now the effect of the sun's attraction on this ring is the same, during a year, whether we suppose the earth to move round the sun, or the sun to move round the earth. Let us then suppose the sun to move round the earth in the circle *a SV*. While the sun is moving from *a* through *S* to *V*, that is, during half the year, the sun acts successively on all the parts of the ring from *A* though *C* to *B*. This action tends to draw the ring into the plane of the ecliptic; and the effect is such as to make it cut the ecliptic somewhere at *x*, and not at *B*, where it did before. So while the sun is going the other half of its orbit, it acts in the same manner on the other half of the ring; and makes it cut the ecliptic somewhere at *d* instead of *A*. Thus the equinoxes are constantly

shifting backward. For the effect we have supposed on this ring, detached from the earth, actually takes place while it is attached to the earth, and forms a part of it.

192. As the equinoctial points move backward, and the sign *Aries* always begins at one of them, and all the other signs of 30° each follow Aries in order, it follows that all the signs of the ecliptic or zodiac move backward with the equinoxes. Consequently stars, which are in one sign at one time, will be in the succeeding one at another. Hence comes the fact spoken of No. 54. The *sign Aries* nearly coincides with the *constellation Pisces;* and *Taurus* with the *constellation Aries,* and so on. When these names were given to the signs and constellations, probably each sign coincided with the constellation of the same name; but on account of the precession of the equinoxes, there is now about one sign or 30° difference. In about 2000 years there will be a difference of two signs or 60°.

SECT. VI.

Of the Tides.

193. Oceans are observed to have a regular rising and falling of their waters, which are called *tides.* There are two tides in about 25 hours. These are occasioned by the attraction of the moon; but affected also by that of the sun.

194. Let *M* (Pl. IX, fig. 4,) be the moon revolving in its orbit; *E* the earth covered with water. The moon, drawing the earth to itself, affects the solid parts of it, just as if its whole weight were in a single point in or near the centre *E*. Now the waters at *A* are nearer the moon than the point *E*, and are consequently

more attracted than the earth. Hence the waters are heaped up under the moon at *A*. But the waters on the opposite side at *B* are less attracted than the earth; consequently the earth is drawn away from them, and they are heaped up at *B*. When the waters are heaped up at *A* and *B*, it is plain they must recede from the intermediate points *C* and *D*.

195. Thus while the earth turns on its axis, any particular place as *A* has two tides, while passing from under the moon till it comes under the moon again. But while the earth is turning on its axis, the moon advances in its orbit, so that the earth must a little more than complete its rotation before the place *A* comes under the moon. This makes high or low water at any place about 50 minutes later one day than on the preceding.

196. It is obvious, that the waters directly under the moon are nearer to it than those any where else; consequently are more attracted. And as the moon's orbit differs but little from the ecliptic, the moon cannot be but about 29° from the equator, generally it is much less. Hence the waters about the equator are more attracted, and of course the tides are higher than towards the poles. At or near the poles tides must cease.

197. The sun attracts the waters as well as the moon. But the difference between the distance of the centre and surface of the earth from the sun, compared with the whole distance of the earth from the sun, is so small, that the sun acts on the waters very nearly as it does on the solid land; and consequently produces little tide. When the moon is at full or change, it acts with the sun; that is, the sun and moon tend to raise tides at the same places. Hence tides are then very high, and are called *spring* tides. But when the moon is in quadrature (Pl. IX, fig. 5,) the sun and moon

tend to raise tides at different places, and counteract each other's effects. The moon raises tides at *C* and *D*, and the sun *tends* to raise them at *A* and *B*. But the sun does not raise tides; its only effect is to diminish or increase those of the moon. Tides, when the moon is in quadratures, are very low, and are called *neap* tides.

198. As the sun is always in the ecliptic, and of course is never more than 23½° from the equator, his influence is joined with that of the moon in making tides high at the equator, and lower towards the poles. Hence, if the earth were a perfect globe, and had no excess of matter nearer the equator, the constant action of the sun and moon on the waters of the ocean would keep the equatorial region constantly immersed.

199. But spring tides are not always equally high at the same place. When the sun and moon are in the equator, their combined effect on the water is greatest. This is at the time of the equinoxes. But as the earth is nearer the sun in winter than in summer, and thereby the sun's action is increased, therefore our highest spring tides are usually a little after the autumnal equinox, and little before the vernal.

200. It is to be noticed, that tides are not at their height when the moon is in the meridian, as would appear from the figures; but this takes place one or two hours after the moon has passed the meridian, because she continues to attract the water during that time.

201. Besides the continually varying, co-operating, or contrary attraction of the sun and moon, there are other causes which affect the time and height of full tide. Strong winds, blowing in a particular direction, and for a long time, produce currents in the ocean, which greatly affect the regular tides. Different places, also equally subject to the moon's action, will have ma-

terially different tides; owing to currents in the ocean, to the position of the neighbouring coast, &c. Continents stop the tides in their course from east to west; consequently, tides are generally higher on an eastern coast than on a western. Thus it is supposed, that the water in the Gulf of Mexico is several feet higher than on the other side of the isthmus; and Napoleon says, (*Voice from St. Helena,*) "I had the Red Sea surveyed, and found that the waters of it were thirty feet higher than the Mediterranean when the waters were highest, but only twenty-four feet at the lowest." In mouths of rivers and bays opening eastward, and growing narrower inland, tides rise to a great height. At the mouth of the Indus, tides rise thirty feet; and in the bay of Fundy, sometimes to the astonishing height of sixty feet. They are remarkably high on the coast of Malay, in the strait of Sunda, and in the Red Sea. In the Mediterranean and Baltic, which have very narrow inlets, and open westward, scarce any tide is perceptible. Hence the Greeks and early Romans were ignorant that any such phenomenon existed.

202. In narrow rivers, the tides are frequently very high and sudden, from the resistance of the banks. The tide is said to enter the river Severn in England sometimes with a head ten feet in height. In rivers where there are many obstructions arising from banks, shallows, and sinuosities, there are not unfrequently several tides at different places. Thus in the river Thames, it is high tide at London and at the Nore (mouth of the river) at the same time; while between these places, there is low tide. The same, according to Dr. Franklin, takes place in the Delaware river. In the river Amazon, in South America, where the tide flows up 500 miles, it is said there are no fewer than seven high tides at various distances, and of course, low tides between them, all at the same time.

APPENDIX.

SECT. I.

Of Meteors.

203. Of the origin and real nature of those bodies, which are known to every one as *falling stars* or *meteors*, and of which many may be seen during almost every clear evening, we are nearly or quite as ignorant as were our progenitors three thousand years ago. Instead therefore of conjectures on these points, we shall confine ourselves to the description of a few of the most remarkable phenomena of this kind.

204. Messrs. Humboldt and Bonpland while at Cumana, in South America, witnessed a very remarkable appearance of meteors. The former thus describes it:—"The night of the 11th November, 1779, was cool and extremely beautiful. Toward the morning, from half after two, the most extraordinary luminous meteors were seen towards the east. Bonpland, who had risen to enjoy the freshness of the air in the gallery, perceived them first. Thousands of bolides (fire-balls) and falling stars, succeeded each other during four hours. Their direction was very regular from north to south. They filled a space in the sky extending from the true east 30° towards the north and south. Some of them attained a height of 40°; and all exceeded 25° or 30°. There was very little wind, and no trace of clouds to be seen. Bonpland relates, that from the beginning of the phenomenon, there was not a space in the firmament equal in extent to three diameters of the moon, which was not filled at every instant with bolides and falling stars. All these meteors left luminous traces from 5° to 10° in length; and the phosphorescence of

these traces, or luminous bands, lasted seven or eight seconds. The bolides seemed to burst as by explosion; but the largest, those from 1° to 1° 15′ in diameter (*the mean diameter of the sun is* 30′ 42″,) disappeared without scintillation, leaving behind them phosphorescent bands, exceeding in breadth 15′ or 20′.

205. "These bolides were visible at the same time on the frontiers of Brazil, a distance of 230 leagues from Cumana. I was therefore powerfully struck at the immense height, which they must have attained. But what was my astonishment, when at my return to Europe, I learnt, that the same phenomenon had been perceived on an extent of the globe of 64° of latitude, and 91° of longitude; at the equator in South America, at Labrador and Greenland, and in Germany!

206. "A phenomenon analogous to that of the 12th of November, was observed thirty years before, on the table land of the Andes, in a country studded with volcanoes. At the city of Quito, there was seen, in one part of the sky, above the volcano of Gayamba, so great a number of falling stars, that the mountain was thought to be in flames. This singular sight lasted more than an hour. The people assembled in the plain of Exico, where a magnificent view presents itself of the highest summit of the Cordilleras. A procession was already on the point of setting out from the convent of St. Francis, when it was perceived, that the blaze of the horizon was caused by fiery meteors, which ran along the skies in all directions, at the altitude of 12° or 13°."

207. Meteors are often seen and heard to burst; and the explosion is not unfrequently followed by the fall of masses of stone. These are denominated *Aerolites*. They often descend with such force as to bury themselves several feet in the earth. Cardan tells us, that in 1510, a great fire was seen in the heavens about

three o'clock, and stones fell about five o'clock. He adds, that he himself saw 120 stones fall; of which one weighed 120 pounds, and another sixty. It is related by Dr. Halley, that on the 21st May, 1676, a fire-ball was seen to come from Dalmatia, proceeding over the Adriatic sea; it passed obliquely over Italy, where a hissing noise was heard. It burst S. S. W. from Leghorn, with a terrible report, and the pieces are said to have fallen into the sea with the same sort of noise, as when red hot iron is immersed in water.

A very particular and interesting account of Meteors and Aerolites may be found in WONDERS OF THE WORLD, *an American edition of which has recently been published.*

We shall close this section with an account of a meteor which was seen in various parts of New England on the morning of the 14th of December, 1807; and which burst near the town of Weston, in Connecticut. The facts relating to it were collected and arranged by Professors Silliman and Kingsley, and published in the American Register, Vol. II; from which work the following account is collected:—

"This meteor, which excited alarm in many, and astonishment in all, first made its appearance in Weston, about a quarter or half past six o'clock, A. M., on Monday, the 14th Dec. The day had merely dawned, and there was little or no light, except from the moon, which was just setting. Judge Wheeler was passing through the enclosure adjoining his house, with his face to the north, and his eyes on the ground, when a sudden flash, occasioned by the transition of a luminous body across the northern margin of the clear sky, illuminated every object, and caused him to look up. He immediately discovered a globe of fire, just then passing behind a cloud, which was very dark and obscure, although it did not entirely hide the meteor.

"In this situation its appearance was distinct and well defined, like that of the sun seen through a mist. It appeared about one half or two thirds the diameter of the full moon. This description of its apparent magnitude is vague, but it was impossible to ascertain what angle it subtended. Its progress was not so rapid as that of common meteors and shooting stars. When it passed behind the thinner clouds, it appeared brighter than before; and when it passed the spots of clear sky, it flashed with a vivid light, yet not so intense as the lightning in a thunder storm, but rather like what is commonly called *heat lightning*. Its surface was apparently convex.

"Where it was not too much obscured by thick clouds, a conical train of paler light was seen to attend it waving, and in length about ten or twelve diameters of the body. In the clear sky a brisk scintillation was observed about the body of the meteor, like that of a burning fire-brand carried against the wind.

"It disappeared about fifteen degrees short of the zenith, and about the same number of degrees west of the meridian. It did not vanish instantaneously, but grew, pretty rapidly, fainter and fainter, as a red hot cannon ball would do, if cooling in the dark, only with much more rapidity. When the meteor disappeared, there were apparently three successive efforts or leaps of the fire-ball, which grew more dim at every throe, and disappeared with the last.

"There was no peculiar smell in the atmosphere, nor were any luminous masses seen to separate from the body. The whole period between its first appearance and total extinction was estimated at about thirty seconds.

"About thirty or forty seconds after this, three loud and distinct reports, like those of a four pounder near at hand, were heard. They succeeded each other with as much rapidity as was consistent with distinctness, and all together did not occupy three seconds. Then followed a rapid succession of reports less loud, and running into each other, so as to produce a continued rumbling, like that of a cannon ball rolling over a floor, sometimes louder, and at other times fainter; some compared it to the noise of a waggon, running rapidly down a long and stony hill; or, to a volley of musketry, protracted into what is called, in military language, *a running fire*.

"We proceed to detail the consequences which followed the explosions and apparent extinction of this luminary. We allude to the fall of a number of masses of stone in several places, principally within the town of Weston. The places which had been well ascertained at the period of investigation were six. The most remote were about nine or ten miles distant from each other, in a line differing little from the course of the meteor. It is therefore probable that the successive masses fell in this order, the most northerly first, and the most southerly last. We think we are able to point out three principal places where stones have fallen, corresponding with the three loud cannon-like reports, and with the three leaps of the meteor. There were some circumstances common to all cases. There was in every instance, immediately after the explosions had ceased, a loud whizzing or roaring noise in the air, observed at all the places, and, so far as was ascertained, at the moment of the fall. It excited in some the idea of a tornado, in others of a large cannon-shot in rapid motion; and it filled all with astonishment and apprehension of some impending catastrophe. In every instance, immediately after this, was heard a sudden and abrupt noise, like that of a ponderous body striking the ground in its fall. Excepting one, the stones were more or less broken. The most important circumstances of the particular cases were as follows:—

"1. The most northerly fall was within the limits of Huntington, on the border of Weston, contiguous to the house of Mr. Merwin Burr. Mr. Burr was standing in the road in front of his house when the stone fell. The noise produced by its collision with a rock of granite, on which it struck, was very loud. Mr. Burr was within fifty feet, and immediately searched for the body, but, it being still dark, he did not find it till half an hour after. By the fall some of it was reduced to powder, and the rest of it was broken into very small fragments, which were thrown around to the distance of twenty or thirty feet. The granite rock was stained at the place of contact with a deep lead colour. The largest fragment which remained did not exceed the size of a goose egg, and this, Mr. Burr found to be still warm to his hand. There was reason to conclude, from all the circumstances, that this stone must have weighed about twenty or twenty-five pounds

"2. The masses projected at the second explosion seem to have fallen principally at and in the vicinity of Mr. William Prince's in Weston, distant about five miles, in a southerly direction, from Mr. Burr's. Mr. Prince and family were still in bed, when *they heard a noise like the fall of a very heavy body immediately after the explosions*. They formed various unsatisfactory conjectures concerning the cause, nor did even a fresh hole made through the turf in the door yard, about twenty-five feet from the house, lead to any conception of the cause, or induce any other inquiry than why a new post hole should have been dug where there was no use for it. So far were this family from conceiving of the possibility of such an event as stones falling from the clouds. They had indeed formed a vague conjecture that the hole might have been made by lightning, but would probably have paid no further attention to the circumstance had they not heard, in the course of the day, that stones had fallen that morning in other parts of the town. This induced them, towards evening, to search the hole in the yard, where they found a stone buried in the loose earth which had fallen in upon it. It was two feet from the surface; the hole was about twelve inches in diameter; and as the earth was soft and nearly free from stones, the mass had sustained little injury, only a few small fragments having been detached by the shock. The weight of this stone was about thirty-five pounds.

"Six days after, another mass was discovered, half a mile northwest from Mr. Prince's. It was in small fragments, having fallen on a globular detached mass of gneiss rock, which it split in two, and by which it was itself shivered to pieces.

"Another mass of thirteen pounds weight had fallen half a mile to the north east of Mr. Prince's Having fallen in a ploughed field, without coming into contact with a rock, it was broken only in two principal pieces, one of which, possessing all the characters of the stone in a remarkable degree, was purchased: for it had now become an article of sale. It was urged that it pleased Heaven to rain down this treasure upon them, and they would bring their thunderbolts to the best market they could. This was, it must be confessed, a wiser mode of managing the business than that which had been adopted by some others, at an earlier period of these discoveries. Strongly impressed with the idea that these stones contained gold and silver, they subjected them to all the tortures of ancient alchemy, and the goldsmith's crucible, the forge, and the blacksmith's anvil, were employed in vain to elicit riches which existed only in the imagination.

"It is probable that these stones last described were all projected at the second explosion.

"3. Last of all, we hasten to what appears to have been the catastrophe of this wonderful phenomenon.

"A mass of stone far exceeding the united weight of all which has been hitherto described, fell in a field belonging to Mr. Elijah Seely, and within thirty rods of his house.

"A circumstance attended the fall of this, which seems to have been peculiar. Mr. Elihu Staples, a man of integrity, lives on the hill, at the bottom of which this body fell, and witnessed the first appearance, progress and explosion of the meteor. After the last explosion, a rending noise, like that of a whirlwind, passed along to the east of his house, and immediately over his orchard, which is on the declivity of the hill. At the same instant a streak of light passed over the orchard in a large curve, and seemed to pierce the ground. A shock was felt, and a report heard like that of a heavy body falling to the earth; but no conception being entertained of the real cause, it was supposed that lightning had struck the ground. Three or four hours after this event, Mr. Seely went into his field to look after his cattle. He found that some of them had leaped into the adjoining enclosure, and all exhibited strong indications of terror. Passing on he was struck with surprise at seeing a spot of ground, which he knew to have been recently turfed over, all torn up, and the earth looking fresh, as if from recent violence. Coming to the place, he found a great mass of fragments of a strange looking stone, and immediately called his wife, who was second on the ground.

"Here were exhibited the most striking proofs of violent collision. A ridge of micaceous schistus lying nearly even with the ground, and somewhat inclining like the hill to the south-east, was shivered to pieces, to a certain extent, by the impulses of the stone, which thus received a still more oblique direction, and forced itself into the earth to the depth of three feet, tearing a hole of five feet in length, and four and a half in breadth, and throwing large masses of turf, and fragments of stone and earth, to the distance of 50 and 100 feet. Had there been no meteor, no explosions, and no witnesses of the light and shock, it would have been impossible for any person contemplating the scene to doubt that a large and heavy body had really fallen from the skies with tremendous momentum.

"This stone was all in fragments, none of which exceeded the size of a man's fist, and was rapidly dispersed by numerous visitors who carried it away at pleasure. Indeed it was very difficult to obtain a supply of specimens of the various stones, an object which was at length accomplished principally by importunity and purchase. From the best information which could be obtained of the quantity of fragments of this last stone, compared with its specific gravity, it was concluded that its weight could not have fallen much short of 200 pounds. All the stones when first found, were friable, being easily broken between the fingers; this was especially the case where they had been buried in the moist earth, but by exposure to the air they gradually hardened. Such were the circumstances attending the fall of these singular masses.

"The specimens obtained from all the different places are perfectly similar. The most careless observer would instantly pronounce them portions of a common mass, and *different from any of the stones commonly seen on this globe.*"

SECT. II.

Of the different Systems.

208. The systems which were generally received among the ancients were very erroneous. Ptolemy, who has given his name to the earliest known system, supposed the earth to be at rest in the centre of the universe, and all the other heavenly bodies to revolve round the earth in the following order; viz. the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. But this system will not account for the different appearances or phases of Mercury and Venus, and consequently cannot be true.

209. This system was soon qualified in some degree among the Egyptians. They observed that Mercury and Venus were never at a great distance from the sun; whereas, if they revolved round the earth, as they supposed the sun itself did, they would sometimes be in opposition to the sun, as the other planets are. Hence they were led to suppose that Mercury and Venus moved round the sun, as secondary planets move round their primaries, and were at the same time carried with the sun round the earth. This theory accounts for all the phases of Venus and Mercury; but it will not account for the different (direct and retrograde) motions of the exterior planets.

210. Of the ancients, however, the Babylonians, and afterwards Pythagoras, (about 500 years before the Christian era,) are said to have considered the earth a planet, revolving round the sun, like the other planets. Though we can hardly conceive how the truth should have been lost, when once discovered and promulgated, yet this knowledge of the true solar system was very soon lost; and was not revived till about the middle of the sixteenth century. Copernicus, from whom the true system is called *Copernican*, supposed the earth to turn on its axis every day, and revolve round the sun every year. These two motions explain, with the utmost facility, all the phenomena of the stations, motions, and phases of all the other heavenly bodies; whence arises the strongest possible proof of the correctness of his supposition, and confirms beyond a doubt the truth of his system. For nothing can be consistent with itself but truth.

211. Notwithstanding the simplicity of this theory, Copernicus found in his time an able astronomer, who rejected the evidences of the truth of his discovery. Tycho Brahe, a Danish nobleman, was anxious to reconcile the appearances of nature, with the literal interpretation of some passages of scripture. He therefore supposed the earth immoveable in the centre of the orbits of the sun and moon, without any rotation on its axis; but he made the sun the centre of the orbits of all the other planets, which therefore revolved with the sun about the earth. This system is called the *Tychonic.* The principal objection to it is its want of simplicity; also the necessity of supposing that all the heavenly bodies move round the earth every day. Some of the followers of Tycho gave a rotatory motion to the earth, and this was called the *Semi-Tychonic* system. But the Copernican system has now superseded all others throughout Christendom.

SECT. III.

Of Leap Year.

212. The solar year, or the time of the sun's passing from an equinox to his return to the same again, consists of 365 days, 5 hours, 48 minutes, and 57 seconds. Hence it is plain, that if we reckon only 365 days to a *civil* or *common* year, the sun would be in an equinox, say the vernal, later in every succeeding year, than in the preceding, by 5 hours, 48 minutes, and 57 seconds; that is, nearly a quarter of a mean day. So that if the sun entered Aries on the 20 March one year, he would enter it on the 21 four years after, and on the 22 eight years after, and so on. Thus in a comparatively short time, the spring months would come in the winter season, and the summer months in the spring season.

213. To prevent the confusion, which would result from this reckoning, in every fourth year, *generally*, a day is added to February, viz. in such years as may be divided by 4 without a remainder. Such years are called *Bissextile*, or *Leap* years. But this is plainly allowing too much; for the excess over 365 days is not equal to a quarter of a day, by 11 minutes, 3 seconds. This would amount to a whole day in about 130 years. To prevent the error, which would thus result, it was settled by an act of parliament, that the years 1800 and 1900, (though divisible by 4,) should not be leap years. And afterwards the closing year of only every fourth century should be a leap year. If this method be adhered to, the present mode of reckoning will not vary a single day from true time, in less than 5000 years.

SECT. IV.

Of Old and New Style.

214. Among different ancient nations, different methods of computing the year were in use. Some determined it by the revolutions of the moon; some by that of the sun. But none (so far as we know) made proper allowance for deficiencies and excesses. Twelve moons fell short of the true year; 13 exceeded it; 365 days were not enough; 366 were too many. To prevent the confusion resulting from these erroneous estimates, Julius Cæsar reformed the calendar, by making the year consist of 365 days, 6 hours, (which is hence called a *Julian* year,) and made every *fourth* year consist of 366 days. This method of reckoning is called *Old Style.*

215. But as this made the year somewhat too long, Pope Gregory XIII., in order to bring the vernal equinox on the 21 March, ordered 10 days to be struck out of the year 1582; calling the next day after the 4th October, the 15th. And by omitting 3 *intercalary* days in 400 years, he intended that the civil and solar year should keep together. This form of the year is called the *Gregorian Account*, or *New Style.* Though this alteration was immediately adopted throughout the greatest part of Europe, it was not admitted by the English till the year 1752. The error at that time amounted to nearly 11 days, which were taken from the month of September, by calling the 3d of that month the 14th.

SECT. V.

Of Cycles.

216. Under the Art. ECLIPSES, it was stated that the line of the moon's nodes went backwards, completing a

revolution in little less than 19 years. This period is the *Cycle of the Moon*, usually called the *Golden Number*. The conjunctions, oppositions, and other aspects of the moon are within an hour and a half of being the same as they were on the same days of the month 19 years before. Consequently, very nearly the same order of eclipses occur every nineteenth year. *To find the Golden Number for any year, add* 1 *to that year, divide the number by* 19, *and the remainder is the* GOLDEN NUMBER. *If nothing remains, the* GOLDEN NUMBER *is* 19.

217. The *Cycle of the Sun* is a revolution of 28 years; in which time the days of the months return again to the same days of the week; the sun's place to the same signs and degrees of the Ecliptic on the same months and days, so as not to differ a degree in 100 years; and the leap years begin the same course over again, with respect to the days of the week, on which the days of the months fall. *To find the Cycle of the Sun, add* 9 *to the given year, divide by* 28, *and the remainder is the* CYCLE OF THE SUN, *for that year. If nothing remains, the* CYCLE *is* 28.

218. In the subjoined table, the Golden Numbers under the months stand against the days of new moon, in the left hand column. It is adapted chiefly to the second year after leap year, and will indicate the time of new moon, (within 1 day,) till the year 1900. A perfectly correct table of this kind cannot be easily constructed.

To show the use of this TABLE, suppose I want to know nearly the time of the new moon in Oct. 1822. By the above *Rule*, I find the *Golden Number* for this year to be 18. Under the month Oct. in the TABLE, I find the *Golden Number* 18 placed against the 14th day in the left hand column; that is, it is new moon on the 14th day, or near it. The error cannot exceed 1 day.

Days.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	9		9	17	17					11		19
2		17			6	14	14	3	11		19	
3	17	6	17	6			3	11		19	8	8
4	6		6	14	14	3			19	8		16
5		14			3	11	11	19	8		16	
6	14	3	14	3			19			16	5	5
7	3		3	11	11	19		8	16			13
8		11			19	8	8	16	5	5	13	
9	11	19	11	19						13		2
10			19	8	8	16	16	5	13		2	10
11	19	8					5	13	2	2	10	
12	8	16	8	16	16	5				10		18
13					5	13	13	2	10		18	7
14	16	5	16	5			2	10	18	18	7	
15	5		5	13	13	2				7		15
16		13			2	10	10	18	7		15	
17	13	2	13	2			18	7		15	4	4
18	2		2	10	10	18			15			12
19		10			18	7	7	15	4	4	12	
20	10	18	10	18			15			12	1	1
21	18		18	7	7	15		4	12			9
22		7			15	4	4	12	1	1	9	
23	7	15	7	15			12			9	17	17
24			15	4	4	12		1	9			6
25	15	4			12		1	9	17	17	6	
26	4		4	12		1				6		14
27		12		1	1	9	9	17	6		14	
28	12	1	12		9		17	6	14	14	3	3
29	1		1	9		17				3		11
30					17	6	6	14	3		11	
31	9		9				14	3		11		19

SECT. VI.

Of the Dominical Letter.

219. The Dominical Letter for any year is that which is placed against Sunday in common almanacks; and is always one of the seven first of the alphabet. Since a common *Julian* year consists of 365 days, if this number be divided by 7, (the number of days in a week,) there will be 1 remainder. Hence it is obvious, that commonly a year begins one day later in the week, than the preceding one did. Thus, if a year of 365 days begins on *Sunday*, the following year will begin on *Monday*. If Sunday falls on the *first* day of *January*, the *first* letter of the alphabet (A) is the *Dominical Letter*. If Sunday falls on the *seventh* day of *January*, (as it will in the 2d year, unless the 1st be leap year,) then the *seventh* letter of the alphabet (G) is the Dominical Letter. If Sunday falls on the *sixth* day of *January*, (as in the 3d year, unless the 1st or 2d be leap year,) the *sixth* letter of the alphabet (F) is the *Dominical Letter*. Hence it is plain, that if there were no leap years, the *Dominical Letters* would go annually in a retrograde order, thus, G, F, E, D, C, B, A.

220. But *Leap* years have 366 days; which, divided by 7, leaves 2 remainder. Hence, the years following leap years will begin 2 days later in the week, than the leap years did. Thus, if a leap year begins on Monday, (the Dominical Letter being G,) the following year will begin on Wednesday, and the Dominical Letter will be E, F being passed over. To prevent the interruption, which would thus occur in the order of the Dominical Letters, leap years have 2 Dominical Letters; one indicates Sunday till the 24th of *February*, and the other till the end of the year.

221. By *Table I.* at the close of this *Sect.* the Dominical Letter for any year, (New Style,) within 4,000 years following the Christian æra, can be readily found. *Look for the hundreds of years at the head of the column, and for the years below a hundred (to make up the given year) at the left hand.* Thus, if I want to know the Dominical Letter for 1822, I look for the column containing 1800 at the top; and in that column, opposite 22 in the left hand column, I find the Dominical Letter of that year, viz. F. Again, if I want to know the Dominical Letter for 1940, I find the column containing 1900 at top, and in that column, against 40 in the left hand column, are G and F, which are the Dominical Letters for that year. Because there are 2 letters against that year, I know it is a leap year.

222. Having the Dominical Letter for any year, *Table II.* shows what days of every month in the year will be *Sundays;* whence may be readily seen what day of the week falls upon any given day in the year. For under the Dominical Letter at the top are the *Sundays* of that year; and next to the Sundays, on the right, are the Mondays, and next are the Tuesdays, and so on to the last column; from which go to the left hand column, and proceed as before to the right hand. Thus, if I want to know what day of the week falls on the 1st of *Sept.* 1822, I find the Dominical Letter of that year to be F, and under F, against the *Month Sept.* I find the 1st day. Hence the 1st day is Sunday, the 2d Monday, and so on. Again, to know what day of the week will fall on the 15th day of July, 1831, by *Table I.* I find the Dominical Letter of that year is B; in *Table II.* under B, and against July, I find that Sunday falls on the 10th, consequently the 15th will be Friday.

Let the pupil be exercised in solving questions by these TABLES till their application becomes easy.

TABLE 1.

Showing the Dominical Letter, New Style, for 4000 years after the Christian æra.

After Chr.				Hundreds of years.			
Years less than a hundred				100	200	300	400
				500	600	700	800
				900	1000	1100	1200
				1300	1400	1500	1600
				1700	1800	1900	2000
				2100	2200	2300	2400
				2500	2600	2700	2800
				2900	3000	3100	3200
				3300	3400	3500	3600
				3700	3800	3900	4000
				C	E	G	B A
1	29	57	85	B	D	F	G
2	30	58	86	A	C	E	E
3	31	59	87	G	B	D	F
4	32	60	88	F E	A G	C B	D C
5	33	61	89	D	F	A	B
6	34	62	90	C	E	G	A
7	35	63	91	B	D	F	G
8	36	64	92	A G	C B	E D	F E
9	37	65	93	F	A	C	D
10	38	66	94	E	G	B	C
11	39	67	95	D	F	A	B
12	40	68	96	C B	E D	G F	A G
13	41	69	97	A	C	E	F
14	42	70	98	G	B	D	E
15	43	71	99	F	A	C	D
16	44	72		E D	G F	B A	C B
17	45	73		C	E	G	A
18	46	74		B	D	F	G
19	47	75		A	C	E	F
20	48	76		G F	B A	D C	E D
21	49	77		E	G	B	C
22	50	78		D	F	A	B
23	51	79		C	E	G	A
24	52	80		B A	D C	F E	G F
25	53	81		G	B	D	E
26	54	82		F	A	C	D
27	55	83		E	G	B	C
28	56	84		D C	F E	A G	A B

TABLE II.

Showing the days of the months, for both Styles, by the Dominical Letters.

Week days.	A	B	C	D	E	F	G
January 31 October 31	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	31				
Feb. 28–29 March 31 November 30				1	2	3	4
	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30	31	
April 30 July 31							1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
	30	31					
August 31			1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	31		
September 30 December 31						1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
	31						
May 31		1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
	28	29	30	31			
June 30					1	2	3
	4	5	6	7	8	9	10
	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	

SECT. VII.

Of Epact.

223. A Julian year consists of 365 days, 6 hours, and a lunar year, of 12 moons, consists of 354 days, 8 hours, 49 minutes. This difference of nearly 11 days between a solar and a lunar year is the *Annual Epact.* Since the epact of one year is 11 days, the epact of two years is 22 days, of three years is 33 days, or rather 3 days; being 3 days over a complete lunation. Hence the epact of four years is 14 days. Thus by yearly adding 11, and casting out the 30s for intercalary lunations, (for when 30 is cast out, the lunar year must consist of 13 lunations,) it will be found, that on every 19th year 29 remains; which is reckoned a complete lunation, and the epact is 0. Thus the cycle, or succession of epacts, expires with the Golden Number, or lunar cycles; and on every 19th year the solar and lunar year begin together. By the epact of any year, the moon's age, or the number of days since her change, is at once seen, for the first day of January. In the following TABLE is exhibited the Golden Numbers, with the corresponding epacts, till the year 1900 of the Christian æra.

TABLE.

Golden number	Epact.	Golden number	Epact.	Golden number	Epact.	Golden number	Epact.
1		6	XXV.	11	XX.	16	XV.
2	XI.	7	VI.	12	I.	17	XXVI.
3	XXII.	8	XVII.	13	XII.	18	VII.
4	III.	9	XXVIII.	14	XXIII.	19	XVIII.
5	XIV.	10	IX.	15	IV.		

224. The INDICTION is a revolution of 15 years, used only by the Romans for indicating the times of certain

payments made by the subjects to the Republic. By the multiplication of the Cycle of the Sun (28 years) into the Cycle of the Moon (19 years) and the Indiction (15 years) arises the *Great Julian Period*, consisting of 7980 years.

SECT. VIII.

PROBLEMS.

A few of the most useful and interesting *Problems* are here inserted, for such pupils as have globes at hand, and instructers, who can point out and explain the use of the different circles and appurtenances belonging to them.

ART. 1.

Problems to be solved by the Terrestrial Globe.

225. PROB. 1.—*To find the latitude of any given place.*

Bring the place to the graduated side of the brazen meridian, and the degree of the meridian over the place is the latitude.

1. What is the latitude of Boston? Ans. 42° 28′ N.

2. Find the latitude of

Amsterdam,
Aleppo,
Alexandria,
Athens,
Bourbon isl.
Bayonne,
Barbadoes isl.
Canton,
Cairo,
Constantinople,
Florence,
Cape Farewell,
C. of Good Hope,
Lima,
New Orleans,
Naples,
Panama,
Paris,
Quebec,
Rome,
Stockholm,
Savannah,
Tripoli,
Upsal,
Vienna,
Warsaw,
Washington.

226. PROB. II.—*To find the longitude of a given place.*

Bring the place to the brazen meridian, and the degree of the equator under the meridian is the longitude.

1. What is the longitude of Petersburg? Ans. 30° 15′ E.

2. What is the longitude of Philadelphia? Ans. 75° 15′ W.

3. Find the longitude of the places mentioned in the preceding number.

227. Prob. III.—*To find the difference of latitude between any two places.*

Find the latitude of each place, by Prob. I. If both are north, or both south latitude, subtract the less from the greater; but if one be north and the other south, add them together, and the result will be the answer.

1. What is the difference of latitude between Petersburg and Philadelphia? Ans. 20°.

2. What is the difference of latitude between Boston and Cape Horn? Ans. 97° 30′.

3. Required the difference of latitude between

London and Rome,
Madrid and Moscow,
Quebec and N. Orleans,
Pekin and Lisbon,
Calcutta and Delhi,
Hague and Lima,
Panama and Valparaiso,
Boston and Montreal,
Edinburgh and Baltimore,
Cape Cod and Cape Henry,
Halifax and Canary Islands,
Gibraltar & Cape of G. Hope.

228. Prob. IV.—*To find the difference of longitude between any two places.*

Find the longitude of each place by Prob. II. If both be in east, or both in west longitude, subtract the less from the greater, and the result is the answer. But if one be east and the other west, add them together, and if the sum be less than 180°, it is the answer; but if more, take it from 360°, and the remainder is the answer.

Find the difference of longitude between the places mentioned in the preceding number.

229. **Prob. V.**—*To find the distance in miles between any two places on the globe.*

Lay the quadrant of altitude over both places, and it will show the number of degrees, which multiply by $69\frac{1}{2}$, and it will give the distance in miles.

1. What is the distance between London and Jamaica? Ans. $67\frac{1}{2}°$, or 4691 miles.

2. What is the distance between

Cadiz and Petersburg,
Cape Horn and Good Hope,
New York and London,
Charleston and Fez,
Washington and Madrid,
Philadelphia and Venice,
Cuba and Cyprus,
London and Bombay?

230. **Prob. VI.**—*The hour of the day at any place being given, to find what o'clock it is at any other place.*

Bring the place, where the hour is given, to the brazen meridian; set the index to the given hour, then turn the globe till the proposed place comes under the meridian; the index will point to the hour required.

Note. If the place required be east of the given place, turn the globe westward; if to the west, turn the globe eastward.

1. When it is 12 o'clock at noon, in London, what is the time at Mauritius and Philadelphia?

Ans.—Four P. M. at Mauritius, and 7 A. M. at Philadelphia.

2. When it is 8 o'clock A. M. at Boston, what is the time at Acapulco and Cape Farewell?

Ans.—6 A. M. at Acapulco, and 10 A. M. at Cape Farewell.

3. When it is midnight at Boston, what o'clock is it at

Paris,
Rome,
Petersburg,
Canton,
Calcutta,
Cairo,
New Orleans,
Rio Janeiro,
Ascension Island?

4. When it is noon at Lisbon, what is the hour at

Quebec,
Mexico,
Cape Horn,
Bermudas,
Jerusalem,
Cape Comorin,

Pekin, St. Helena, Athens,
Babelmandel, Botany Bay, Tripoli?

231. Prob. VII.—*The hour of the day being given at any place, to find all the places on the globe where it is any other given hour.*

Bring the place to the brazen meridian, and set the index to the hour of that place; turn the globe till the index points to the other given hour, then all the places under the meridian are the places required.

1. When it is 12 at noon, in London, at what places is it 8 A. M.?

Ans.—Cape Canso, Martinico, Trinidad, &c.

2. When it is 2 P. M. in London, where is it half past 5 P. M.?

Ans.—Caspian Sea, Socotra, Madagascar, &c.

3. When it is 5 A. M. at Madrid, where is it noon?
4. When it is noon at New York, where is it 5 P. M.?
5. When it is 10 A. M. at New York, where is it noon?
6. When it is noon at Paris, where is it midnight?
7. Does the sun rise first upon Cape Farewell or New Orleans on March 21?
8. Does the sun set soonest at the Bermuda islands, or in the gulf of California? How much?
9. What places have 6 o'clock A. M. when it is noon at the Falkland islands?
10. When it is noon at Lisbon, at what places is it 3 o'clock in the afternoon, and at what places is it 6 o'clock in the forenoon?

232. Prob. VIII.—*To find the antipodes of any place.*

Bring the given place to the meridian, and find its latitude; set the index to 12, and turn the globe till the index points to the other 12; then the same degree of latitude on the other side of the equator shows the antipodes, thus:

1. What is the antipodes of London?

Ans.—The south part of New Zealand.

2. What is the antipodes of the Bermudas?

Ans.—South west part of New Holland.

3. What is the antipodes of the Society Islands?

Ans.—The Red Sea.

4. What is the antipodes of

Boston,
Terra del Fuego,
Caspian Sea,
Egypt,
Spain,
Persia?

233. Prob. IX.—*To find at what rate per hour the inhabitants of any given place are carried by the revolution of the earth on its axis.*

Find how many miles make a degree of longitude in the latitude of the given place, (see Table, page 45.) which multiply by 15 for the answer.

At what rate per hour are the inhabitants of the following places carried by the motion of the earth on its axis?

Petersburg,
London,
Boston,
Quito,
Cape of Good Hope,
Calcutta,
Delhi,
Batavia?

234. Prob. X.—*The day of the month being given, to find the sun's place or longitude in the ecliptic, and its declination.*

Look for the given day in the circle of months on the horizon, and opposite to it in the circle of signs, are the sign and degree the sun is in on that day. Find the same sign and degree in the ecliptic, and it will be the sun's place or longitude; bring this place to the meridian, and you will have the declination.

1. What is the sun's longitude and declination on the 22 of February?

Ans.—337° 30′ or 4° 30′ in Pisces; its declination is 10° south.

2. What is the sun's longitude and declination on the 15 of April?

Ans.—25° 30′, in Aries; its declination 10° north.

3. When does the sun enter each of the signs?

4. What is the sun's declination on the 21 of June?

5. What is the sun's place and declination on the 22 of December?

6. What is the sun's place in the ecliptic, and its declination, on each of the following days:

March	30	July	13	November	2
April	4	August	8	December	29
May	12	September	16	January	7
June	9	October	5	February	18

235. PROB. XI.—*To rectify the globe for the latitude, zenith, and sun's place on any day.*

1. FOR THE LATITUDE. Elevate the pole till the horizon cuts the brass meridian in the degree corresponding to the latitude of the place.

2. The given place is then in the zenith.

3. Then (by Problem X.) find the sun's place for the given day, bring it to the meridian, and set the index to 12.

Note. If the place be in north latitude, elevate the north pole, if in south latitude, elevate the south pole.

1. Rectify the globe for the latitude of London, on the 10 of May.

In this case elevate the north pole 51° 30′, then London will be in the zenith, over it screw the quadrant of altitude; the 10 of May on the horizon answers to the twentieth degree of Taurus, which find on the ecliptic, and bring it to the meridian, and set the index to 12. This is the position of the globe, as it appears to the inhabitants on the 10 of May.

2. Rectify the globe for

New York	12 January,	Madrid	16 Sept.
Boston	6 Feb.	Cape Horn	15 Nov.
Constantinople	9 March,	St. Jago (Chili)	14 Dec.
Petersburg	10 April,	Gallipagos	19 Oct.

236. Prob. XII.—***The month and day of the month being given, to find all those places on the globe, which will have a vertical sun on that day.***

Find the sun's place in the ecliptic (Prob. X.) and bring it to the meridian; turn the globe round, and all the places that pass under that degree of the meridian will have a vertical sun on that day.

1. Find all the places which have a vertical sun on the 22 of February.

Ans.—Peru, Amazonia, Angola, New Guinea, Queen Charlotte's Island, &c.

2. What places have a vertical sun on the 9 of May?

3. What places will have a vertical sun on the

21 of March,	23 of Sept.
21 of June,	22 of Dec.?

237. Prob. XIII.—***To find at what hour the sun rises and sets at any place, any day in the year, and the length of the day and night at that place.***

1. Rectify the globe (by Prob. XI.) for the latitude of the place; find the sun's place in the ecliptic (by Prob. X.) and bring it to the meridian, and set the index to 12; bring the sun's place to the eastern edge of the horizon, and the index will show the hour of rising; bring it to the western edge of the horizon, and the index will show the hour of setting.

2. Double the time of sun-rising, and it will give the length of the night; double the hour of sun-setting, and it will give the length of the day.

1. What time does the sun rise and set at New York, on the 10 of May, and what is the length of the day and night?

Ans.—It rises 56 minutes past 4; sets 4 minutes after 7; length of the night 9h. 52m.; of the day 14h. 8m.

2. What is the time of sun-rising and sun-setting, and the length of the day and night, at each of the following places, on the day mentioned?

Boston	7 Nov.	Cape Horn	1 Dec.
Washington city	4 May,	Rome	5 January,
Constantinople	14 June,	Naples	9 Oct.
London	15 July,	Canton	8 August.
Rio Janeiro	8 Sept.		

238. Prob. XIV.—*To find the length of the longest and shortest days and nights in any part of the world.*

1. If the place be in the northern hemisphere, rectify the globe for the latitude of the place, bring the first degree of Cancer to the meridian, and proceed as in the last problem.

2. If the place be in the southern hemisphere, bring the first degree of Capricorn to the meridian, and proceed as before.

1. What is the length of the longest day and shortest night at New York?

Ans.—Longest day 14h. 56m. shortest night 9h. 4m.

Note. The shortest night of any place is equal to its shortest day, when the sun is on the other side of the equator, and its longest day to its longest night.

2. What is the length of the longest day and shortest night at each of the following places?

Boston,
Philadelphia,
Mexico,
Halifax,
Quebec,
Augusta,
New Orleans,
Quito,
Chiloe,
London,
Iceland,
Cape Verd,
Suez,
Bombay,
Canton,
Madagascar,
Abo,
Berlin,
River Zaire,
Botany Bay,
Madras,
Mouth of Columbia river,
Hudson's Bay,
Dardanelles,
Azores,
Isles of Georgia.

Their shortest day and longest night are shown by the above note.

239. **Prob. XV.**—*The month and day of the month being given, to find those places where the sun does not set, and where it does not rise on the given day.*

Find the sun's declination (by Prob. X.) elevate the pole for the declination, in the same manner as for the latitude; turn the globe on its axis, and on the places round the pole, above the horizon, the sun does not set; and on the places round the other pole, below the horizon, the sun does not rise, on that day.

1. How much of the south frigid zone is darkened, and how much of the north frigid zone is enlighted, on the 20 of May?

Ans.—20° round each pole.

2. On which pole does the sun rise on Nov. 6.

3. Which frigid zone, and how much of it, has constant day, on August 4?

4. How much of the south frigid zone has constant day on the following days?

October 1,
October 20,
Nov. 19,
Dec. 22,
Jan. 9,
Feb. 10,
Feb. 20,
March 1.

5. What days in the year does the sun shine equally on both poles?

Art. 2.

Problems to be solved by the celestial globe.

240. **Prob. XVI.**—*To find the right ascension of the sun or a star.*

Bring the sun's place in the ecliptic or the star to the brass meridian, then the degrees of the equinoctial under the meridian, reckoning from Aries eastward, is the right ascension.

1. What is the sun's right ascension on the 19 of April? Ans.—27° 30′.

2. What is the sun's right ascension on the 1 Dec.? Ans.—247° 50′.

3. What is the sun's right ascension on
Nov. 6,
March 4,
April 20,
June 16,
July 29,
May 7,
August 10,
Sept. 14,
Oct. 23,
Dec. 10?

4. What is the right ascension of Aldebaran?
Ans.—66° 6′.

5. What is the right ascension of
Alioth,
Arcturus,
Bellatrix,
Castor,
Algol,
Fomalhaut,
Hyades,
Pleiades,
Procyon,
Regulus,
Rigel,
Sirius,
Antares,
Pollux?

241. Prob. XVII.—*To find the declination of the sun or a star.*

Bring the sun's place in the ecliptic or the star to the brass meridian, and the degree of the meridian over that place will be the declination.

1. What is the declination of the sun, April 19?
Ans.—11° 19′.

2. What is the sun's declination,
January 18,
February 12,
March 2,
April 12,
May 23,
June 21?

3. What is the declination of Aldebaran?
Ans.—16° 6′.

4. What is the declination of
Atair,
Algenib,
Arcturus,
Procyon,
Regulus,
Regel?

242. Prob. XVIII.—*The latitude of the place, the day and hour being given, to place the globe so as to represent the appearance of the heavens at that time at the place; and to point out the situations of the several stars.*

Elevate the pole for the latitude of the place; find the sun's place in the ecliptic, and bring it to the meridian, and set the index to 12; if the time be afternoon, turn the globe westward; if in the forenoon, turn it eastward, till the index points to the given hour. The surface of the globe then represents the appearance of the heavens at that place.

1. Represent the appearance of the heavens for Jan. 13, 4 o'clock A. M. and 8 o'clock P. M.
2. August 30, at 9 o'clock P. M.
3. November 3, at 3 o'clock A. M.
4. May 16, at midnight.

243. Prob. XIX.—*To find the latitude or longitude of a given star.*

Screw the quadrant on the pole of the ecliptic, bring the star to the meridian, and the degrees of the quadrant between the ecliptic and star, show the latitude, and the degree of the ecliptic under the graduated edge of the quadrant is the longitude.

1. What is the latitude and longitude of Arcturus? Ans.—Latitude 31° north. Longitude 201°.
2. What are the latitudes and longitudes of

Fomalhaut,	Canis Major,
Canis Minor,	Regulus?

QUESTIONS.

Sect. I.

1 What does the *true* Solar System consist of?
2 How do primary planets and comets differ from secondary planets, moons, or satellites?
3 How many primary planets are there?
4 Name them.
5 How many secondary planets are there?
6 How are they distributed in the solar system?
7 Is the number of the comets known?
8 What is the centre of the solar system?
9 In what direction do primary planets move round the sun?
10 What is the path of a heavenly body called?
11 In what direction do secondary planets revolve?
12 Have comets a particular direction?
13 What is the form of the planets' orbits? Explain.
14 Is the sun in the centre?
15 What is the *lower* focus?——16 What is the *upper*?
17 When is a heavenly body said to be in its perihelion?
18 When in its aphelion?
19 When is the moon said to be in perigee?——20 When in apogee?
21 What is the *eccentricity* of an orbit? (see fig.)
22 What is the figure of all the planets, except the Earth?
23 How is this known of all except the Earth?
24 How is it known of the Earth?
25 Have all the planets another motion besides that round the Sun?
26 What are *axes?*
27 Do large bodies, or small ones, generally turn quickest on their *axes?*
28 What are the extremities of an axis called?
29 Does the Sun *appear* to describe the same circle among the stars, which the Earth describes?
30 With what difference? Illustrate.
31 What is this circle called?
32 What is the plane passing through this circle called?
33 How many degrees in a circle?
34 How many minutes in a degree?——35 Seconds in a minute?
36 How many signs in the Ecliptic?

37 How many degrees in each sign?
38 Repeat the signs in order. (See fig.)
39 In what sign is the aphelion of each planet? (See frontispiece.)
40 Do all the primary planets revolve in the Ecliptic?
41 What is the Zodiac? Describe it.
42 Are all the planets always in the Zodiac?
43 Mention the exceptions.
44 What are nodes?——45 Descending?——46 Ascending?

SECT. II.

47 By what light are the planets seen?
48 What does the different distances of the planets from the sun occasion?
49 By what law do heat and light decrease? Explain.
50 Can this be proved?——51 Prove it.
52 What variation in the appearance of the Sun's disk?
53 What does the alternate appearance and disappearance of spots on the Sun's disk prove?
54 In what time does the Sun turn on his axis?
55 Do the spots change in appearance?
56 Is their cause known?
57 What is the zodiacal light? Describe it.
58 When is it most distinct?
59 In what region is it always visible
60 Is its cause known?

SECT. III.

61 Proceeding from the sun, which is the first planet?
62 What is the mean distance of Mercury from the Sun?
63 In what time does it revolve round the sun?—64 Turn on its axis?
65 What is the colour of its light?
66 Why is it not often seen?
67 What is its greatest elongation?
68 What is the degree of heat and light at Mercury, compared with that of the Earth?
69 What would become of water there?

SECT. IV.

70 What is the mean distance of Venus?
71 In what time does it revolve round the sun?
72 In what time does it turn on its axis?
73 What is said of the light reflected by this planet?
74 What is its greatest elongation?
75 What is the comparative portion of heat and light at Venus?

76 When is this planet brightest?
77 What portion of her disk is then illuminated?
78 What is said of her lustre compared with that of the moon?
79 From what circumstance does this arise?
80 What are called *interior* planets?
81 What are called *exterior* planets?
82 When is Venus *morning* star?——83 When *evening*?
84 Illustrate this.
85 If the earth were stationary, how long would Venus be evening star?
86 Illustrate the effect of the earth's motion.
87 How long is Venus morning and evening star?

SECT. V.

88 What is the mean distance of the earth?
89 In what time does it revolve round the sun
90 In what time does it turn on its axis?
91 In what time does the moon revolve round the Earth?
92 What is its distance from the Earth?
93 In what time does it turn on its axis?
94 What is the most obvious fact relating to the Moon?
95 When is the *new moon* exhibited?——96 When the *full moon*?
97 When is it said to change?
98 When is it said to full?
99 Explain the different phases of the Moon by the figure.
100 When is the moon said to be horned?
101 When is she said to be in quadrature?
102 When gibbous?
103 What phases does the Earth exhibit, as seen from the Moon?
104 With what difference?
105 How much larger does the Earth appear to the Moon than the Moon to us?
106 What results from the Moon's turning on its axis in the same time that it revolves round the Earth?
107 What is the consequence?
108 Describe the Moon's surface, as it appears through a telescope.
109 Of what depth and width are some of these excavations?
110 What do these depressions probably resemble?
111 Are any mountains probably volcanic?

SECT. VI.

112 At what distance from the Sun is Mars?
113 In what time does Mars revolve round the Sun?
114 In what time turn on its axis?
115 What is the colour of its light?

116 What is said of the spots sometimes seen on his disk?
117 What is the proportion of heat and light at Mars, compared with ours?

SECT. VII.

118 By whom and where was Vesta discovered?
119 What is its distance from the Sun?
120 In what time does it revolve round the Sun?
121 Is the time of turning on its axis known?
Ask the same questions respecting Juno, Pallas, and Ceres.

SECT. VIII.

122 What is the distance of Jupiter from the Sun?
123 In what time does it complete its revolution?
124 In what time does it turn on its axis?
125 What rank does it hold among the planets?
126 What is said of its light?
127 What is the degree of heat and light at Jupiter?
128 What is its appearance when seen through a telescope?
129 Do these vary?——130 Are they always dark?
131 What is said of the spots?
132 How many satellites has Jupiter?
133 Of what use are their eclipses?
134 How is it ascertained, that light is 8′ coming from the Sun to the Earth?
135 How are the satellites reckoned?
136 What is the size of the third? Fourth?
137 Why could not an observer in Jupiter see Mars and the interior planets?
138 What advantage has a position on Jupiter over one on the Earth?

SECT. IX.

139 At what distance from the Sun is Saturn?
140 In what time does it turn on its axis?
141 In what time revolve round the Sun?
142 What is the degree of heat and light at Saturn?
143 By what is Saturn remarkably distinguished?
144 Describe the rings.
145 How is the surface of Saturn diversified?
146 How many satellites has Saturn?
147 How are satellites reckoned?

SECT. X.

148 When, and by whom was Uranus discovered?
149 What is its distance from the Sun?
150 In what time does it revolve round the Sun?
151 What is the degree of heat and light at Uranus?
152 How many satellites has this planet?
153 What is remarkable in the position of their orbits?
154 What is their *apparent* motion?
155 To what is this probably owing?
156 How are they reckoned?
157 How is it known that the Moon turns on its axis in the same time that she revolves round the Earth? Explain.
158 What has been observed of the seventh satellite of Saturn?
159 What does this prove?
160 What is inferred from the changes of Jupiter's satellites?
161 What hence appears to be a general law of satellites?
162 What singular appearances hence present themselves to the inhabitants of secondary planets?
163 Illustrate this.

SECT. XI.

164 What is the general form of comets' orbits?
165 How did the ancients look upon them?
166 What do the moderns consider them?
167 How are they generally distinguished from the other heavenly bodies?
168 In what direction do the tails extend?
169 Do comets vary in magnitude?
170 What is said of one which was visible at Rome?
171 What of the one observed by Hevelius?
172 What is said of their atmosphere?
173 How many have appeared since the Christian era?
174 Why are the calculations of the periodical times of comets uncertain?
175 Who have successfully predicted the return of comets?

SECT. XII.

176 Is the number of stars known?
177 What is the greatest number visible at a time?
178 Why are we deceived in the number of stars visible at a time?
179 How are they classed?
80 Why may not the distance of the stars be known?

181 What is supposed to occasion, (partly, if not wholly,) the difference in the *apparent* magnitude of the stars?
182 How much more distant from the Sun must the nearest star be than the Earth is?
183 Might the stars have motion without its being noticed?
184 As telescopes are improved, what new phenomena are discovered respecting the stars?
185 State the facts relating to the stars, in No. 50.
186 What is the Galaxy, or Milky-way?
187 What is supposed to occasion it?
188 How many stars did Herschel see in $\frac{1}{4}$ of an hour?
189 What are *nebulæ* supposed to be?
190 What are the stars probably?
191 How is it certain that they do not reflect the Sun's light, like the planets?
192 How are they distinguishable from the planets?
193 What are Constellations?
194 What is said of Orion, and the Pleiades?
195 What is their number?——ancient?——modern?
196 How are stars designated on the globe?
197 How many constellations in the zodiac?
198 How do these differ from the signs?

CHAP. II.

199 What is the Earth's axis?
200 What are the poles?
201 What are *celestial* poles?
202 What is the *pole star*?
203 What is the equator?
204 What are *hemispheres*?
205 What is the *celestial* equator?
206 From what is *latitude* reckoned?
207 What are *parallels* of latitude?
208 Is the number of parallels limited?
209 What is a meridian?
210 Is the number of meridians limited?
211 When are places said to be in different longitudes?
212 What are *celestial* meridians?
213 When it is noon at any place, where is the sun?
214 Illustrate what has been said by the figure.
215 How is the latitude of a place on the earth estimated?
216 Illustrate this by the figure.
217 How is the longitude of one place from another estimated?
218 Illustrate this.
219 What is a Great Circle?
220 What are Less Circles?

221 Is the equator a great or a less circle?——Why?
222 Are parallels great or less circles?——Why?
223 Are meridians great or less circles?——Why?
224 Is there any natural reason, why longitude should be reckoned from one meridian, rather than from another?
225 What, till lately, has been the custom of writers?
226 From what *prime* meridian is longitude now usually reckoned?
227 What is the greatest latitude a place can have? Why?
228 What is the greatest longitude a place can have?
229 From what is latitude of heavenly bodies reckoned?
230 What are *secondaries* to the ecliptic?
231 What are the Poles of the Ecliptic?
232 How far are they distant from the celestial poles?
233 How is the longitude of a heavenly body reckoned?
234 From what point of the ecliptic?
235 What is the *declination* of a heavenly body?
236 What is *right ascension*?
237 State the difference between *celestial latitude* and *declination*.
238 State the difference between *longitude* and *right ascension*.
239 Are degrees of latitude of the same absolute length?
240 What is that length?
241 Are degrees of longitude of the same absolute length?
242 Explain the reason.
243 What is the rule?——*See Italics.*
244 What is the horizon?
245 What is the difference between the *sensible* horizon and the *rational?* Explain.
246 Why is not the difference perceptible?
247 In this treatise, which is meant when the term occurs?
248 What is the Zenith?
249 How far is it from the horizon?
250 What is the Nadir?
251 What are the zenith and nadir sometimes called?
252 How far is the zenith from the celestial equator?
253 Illustrate this by the figure.
254 If the distance of the zenith from the celestial equator be found, what does it show?
255 Does the plane of the horizon change its position as a person changes his place?
256 Illustrate this by the figure.
257 Hence to find the distance of the zenith from the celestial equator, what is necessary?
258 Illustrate the use of the quadrant.
259 How can latitude be found by day?
260 Illustrate this.
261 If the sun be not in the celestial equator what is necessary?
262 Illustrate this by examples.
263 What is the rule respecting declination?
264 What is the common way of ascertaining longitude?

265 Why is not this to be depended upon?
266 How many degrees does the sun appear to pass through in an hour?
267 Do clocks differ, as places are in different longitude?
268 Illustrate this.
269 How can longitude be known, by having the difference of time?
270 Illustrate this.——*Two examples. No.* 76.
271 What is the difficulty in this method?
272 What machines are most uniform in their movements?
273 Why may not these be used at sea?
274 Why may not watches, &c. be made accurate measurers of time?
275 How can time-pieces be corrected at sea?
276 Illustrate by an eclipse of the moon.
277 How frequently is there an eclipse of a satellite of Jupiter?
278 Why may not time-pieces be corrected by these eclipses?
279 What other method of correcting time-pieces is mentioned?
280 Explain the use of the tables.
281 What is still a great desideratum?
282 What encouragement have the English given, to direct the attention of astronomers to this subject?
283 Have any rewards been yet obtained?
284 What is now the greatest reward which can be obtained?

CHAP. III.

SECT. I.

285 What is the *direct* motion of a planet?
286 What is *retrograde* motion?
287 When is the motion of Venus direct? (See fig.)
288 When is it retrograde?
289 When is Venus stationary?
290 When is Venus in her superior conjunction?
291 When in her inferior conjunction?
292 When is the motion of the Earth seen from Venus direct?
293 When retrograde? Illustrate.
294 When is the Earth in opposition?
295 When in conjunction?
296 What motion does each exterior planet exhibit to us?
297 Does Venus and the other planets vary their apparent magnitude?
298 What is the cause of this variation?
299 When does an eclipse of the Sun take place?
300 When does an eclipse of the Moon take place?
301 At the time of an eclipse, where must the Sun, Earth, and Moon be?

302 Why does not an eclipse take place at every full and new Moon?
303 At new or full Moon, how near must the Moon be to the ecliptic to occasion an eclipse?
304 To eclipse the Sun, how near a node must the Moon be, at the time of change?
305 To eclipse the Moon, how near a node must she be at the time of full?
306 Is the Sun or Moon oftenest eclipsed?
307 Why do the inhabitants of any particular place, as Boston, witness more lunar than solar eclipses?
308 What is the figure of the earth's shadow?——309 Why?
310 Does the Moon's shadow ever fall upon a hemisphere of the earth?
311 Does the Moon's shadow ever terminate before it reaches the Earth?
312 When is an eclipse said to be *annular?*
313 When *total?*
314 When *partial?*
315 What is the *penumbra?*
316 What would be the appearance to a person, if he could pass, during an eclipse, from *a* to *D?*
317 Is the inner or outer region of the penumbra darkest?
318 Under the most favourable circumstances, on what portion of the Earth's hemisphere does the penumbra fall?
319 What is the consequence?
320 How is the case different in *lunar* eclipses?
321 What is the consequence?
322 Explain the reason, why a lunar eclipse is visible to all to whom the moon at the time is visible; and why a *solar* one is not.
323 Is it difficult to tell the precise time when a lunar eclipse begins or ends?——324 Why?
325 Is the case similar in solar eclipses?
326 Does one primary planet ever enter into the dark shadow of another?——Why?
327 Is the passage of a superior planet through the Earth's penumbra perceptible to us?———Why?
328 If the Moon's nodes were stationary, how often would one come between the Earth and Sun?
329 How often must an eclipse of the Sun take place?
330 Explain the reason.
331 Is the same true with regard to lunar eclipses?——Why?
332 Are the Moon's nodes stationary?
333 How often may a node be between the Sun and Earth in one year?
334 How long are they in completing a revolution?
335 What is the common number of eclipses in a year?
336 What is the smallest number?
337 What is the greatest?
338 What are *digits?*

SECT. II.

339 What does common experience show?
340 In what case is this effect striking?
341 What occasions day and night?
342 If the line *NS* were always in the circle dividing the light from the dark hemisphere, what would be the consequence?
343 Illustrate this.
344 When is *NS* in this position?
345 What periods are called equinoxes?
346 Which vernal?——autumnal?
347 At the equinoxes, where and when does the Sun rise? set?
348 At other seasons, what is the position of *NS*?
349 Illustrate the effect of this position when the Earth is at Cancer.——When at Capricorn.
350 In all positions what is fact at the equator?
351 When days are longest in N. latitude, how are they in south? *Vice versa?*
352 How many days and nights in a year at the poles?
353 How far beyond a pole can the Sun shine?
354 What are Polar Circles?
355 What are the Tropics?——Of Cancer?——Of Capricorn?
356 What are the Solstices?
357 At the summer solstice, how are days and nights in N. latitude? In S. latitude?
358 At the winter solstice, what is the case?
359 Explain the reason why the Earth turns on its axis once more in a year than we have days.
360 What is a Siderial day?
361 What is a Solar or Natural day?
362 What is the difference between the *periodical* and *synodical* revolution of the Moon? *(See small print.)*

SECT. III.

ART. 1.

363 At what rate does light move?
364 At what rate does the earth move in its orbit?
365 What results from these two motions? Illustrate.
366 What does aberration amount to?

Art. 2.

367 Does the Earth receive a greater degree of heat and light from the Sun at one time than at another?
368 Illustrate this.
369 Does this occasion the seasons?
370 What does occasion the seasons? Illustrate.
371 What is the cause of the different obliquity of the Sun's rays?
372 Explain this effect from Nos. 110 and 111.
373 What other circumstance contributes much to the warmth of summer, &c.?
374 In summer is the sun more powerful in S. latitude than in N.? Why?
375 What compensation for this, in north latitude? Explain.
376 How much longer are summers in north latitude than in south?
377 Why do we not have the greatest heat and cold at the solstices?
378 When is our warmest weather?——coldest?
379 What part of the day is warmest?
380 What is the difference between a *siderial* and a *solar* year?

Art. 3.

381 When is the Sun said to be *slow of* the clock?
382 When *fast* of the clock?
383 What is *mean time*?——*Apparent time*?——*Equation*?
384 What is the first cause of the inequality of natural days?
385 What was ascertained by Kepler?
386 How does it thence follow, that the Sun must pass through a greater portion of his orbit in some days than in others?
387 Illustrate this. (No. 118.)
388 Because the Earth advances in its orbit farther in some days than in others, how does it thence follow that some days must be longer than others? (No. 119.)
389 So far as this cause operates, when would the Sun and clock agree?
390 What is the second cause of the inequality of natural days?
391 Illustrate this. (Nos. 121 and 122.)
392 So far as this cause operates, when would the Sun and clock agree?
393 During what part of the year would the Sun be fast of the clock?
394 When slow of the clock?
395 How often, and when, do the Sun and clocks actually agree?
396 What is the greatest possible difference between mean and apparent time?
397 When does this take place?

Art. 4.

398 What is the mean daily difference in the times of the Moon's rising?
399 What was early observed by the husbandman?
400 Explain the cause of the harvest Moon. (No. 126.)
401 Why do we not notice these variations in the Moon's rising at other seasons?
402 What wonderful accommodation to the wants of the inhabitants in the polar regions is noticed?
403 Do the inhabitants in south latitude have harvest Moons?
404 How do they differ from ours?
405 Does the inclination of the Moon's orbit to the ecliptic vary the effects just treated of?
406 When are these effects increased? When diminished?

Sect. IV.

407 When is a ray of light said to be refracted?
408 Illustrate this.
409 What two circumstances augment refraction?
410 What familiar experiment illustrates refraction?
411 If a ray of light pass through a medium, the density of which increases downwards, what line will it describe?
412 Since the atmosphere is such a medium, what is the consequence?
413 In what direction do we see objects?
414 What is an obvious effect of refraction?
415 Can the inhabitants of Boston ever see the sun and planets in their true place? Why?
416 Does refraction make heavenly bodies appear higher or lower than they really are?
417 Illustrate this.
418 What singular phenomenon does this account for?
419 How does this affect the length of the day?
420 Making how much in a year?
421 Is this effect the same at all places?
422 What is twilight?——and what occasions it?
423 When does it commence and end?
424 What occasions variation in the duration of the twilight?
425 As latitude increases, how is the duration of twilight affected?
426 Is it longer at one season than at another?
427 When is twilight longest, and when shortest at Boston?
428 What is the first appearance of morning twilight usually called?
429 Is the evening or morning twilight longest? Why?
430 Were there no atmosphere, what appearances would take place?
431 When is refraction greatest?

432 How does this fact account for the Sun or Moon appearing oval in the horizon?
433 When the Moon is eclipsed, what renders it visible?
434 Are objects on earth, as well as heavenly bodies, elevated by refraction? Why?
435 What is the most striking effect of this kind?
436 From what is the *horizontal* moon supposed to result?
437 What appears to be the figure of the sky?
438 In judging of the unknown size of an object, what do we first determine?
439 Illustrate this.
440 Do intervening objects assist us in judging of distance?
441 Explain how this fact makes the Moon appear more distant in the horizon than in the zenith?

SECT. V.

442 What is Parallax?
443 Illustrate *parallax* by the figure; also, *true* place, and *apparent* place.
444 Is parallax greatest when the body is in the horizon, or in the zenith?
445 How does distance affect parallax?
446 Does parallax elevate or depress bodies?
447 What is *annual* parallax?
448 Have the fixed stars any apparent parallax?
449 How much more distant from our Sun must they be, than we are?
450 Illustrate how the distance of the Moon from the Earth may be obtained.
451 Did the ancients know the distance of the Earth from the Sun?
452 How was the first approximation to the truth obtained?
453 Illustrate.
454 Why was not this method to be relied on?
455 What method did Dr. Halley devise?
456 What is the *first* mentioned subject which Astronomers had determined by observation?
457 What law is stated, developed by Kepler?
458 From this what could be readily found? Example.
459 What is the *third* mentioned subject?
460 What the *fourth*?
461 Illustrate (Nos. 153 & 154) how the parallax of the Sun can be obtained.

BOOK II.

462 What property is common to every particle of matter?
463 What is this tendency called?
464 Does it differ from weight?
465 When we say a body weighs a pound, what do we mean?
466 Is this tendency uniform?
467 What is the law by which it varies?
468 Illustrate this.
469 How do bodies, containing a different number of particles, affect each other? Illustrate.
470 Is all attraction mutual?
471 What is the centre of gravity of two bodies?
472 How can this be found?
473 What other universal circumstance attends inanimate bodies?
474 Illustrate inertness.
475 State the two universal facts relating to matter.

SECT. I.

476 Supposing a planet in motion, how could gravity cause it to revolve in a circle?
477 How in an ellipse?
478 Explain why the *former* orbit is a circle.
479 When do the centripetal and centrifugal forces balance each other?
480 Explain why the *latter* orbit is an ellipse.
481 Does the Sun revolve round the centre of gravity, as well as the Earth?
482 Is the Sun's motion regular? Why?
483 Does the Moon also revolve round a centre of gravity?
484 How far distant from the Earth's surface is the centre of gravity of the Earth and Moon?
485 What has been ascertained with regard to double stars?
486 What has Dr. Herschel found?
487 Have the stars a peculiar motion?
488 How did Dr. Halley first discover this?
489 What is this motion of the stars called?
490 What facts seem to prove that the Sun has a *proper* motion?
491 Towards what part of the heavens does this motion appear to be directed?
492 What beautiful supposition of Herschel is mentioned?
493 What is probable with regard to nebulæ?
494 To complete the analogy of the universe what is necessary?

SECT. II.

495 Explain the cause of the retrograde motion of the Moon's nodes.

SECT. III.

496 What is an obvious effect of mutual attraction and change of distance?
497 Illustrate.
498 Before the new planets were discovered, did astronomers suspect their existence? Why?
499 Nearly how many corrections are necessary to find the Moon's true place?
500 Explain the effect of the varying attraction of the Sun on the Moon and Earth?
501 Point out the *octants* of the Moon's orbit: ——*syzygies*.
502 In what points of her orbit is the Moon too fast?——too slow?
503 In what point does she move at her mean rate?——504 More than her mean rate?——505 Less than her mean rate?
506 Why is a *lunation* longer in winter than in summer?
507 How much longer is it?
508 What fact is stated as recorded in history?
509 When did the eclipse commence according to our *tables*?
510 Why might not the ancients be mistaken in the time?
511 From this and other discordances what is the conclusion?
512 What did this fact lead astronomers to suppose?
513 What did La Place discover to be the cause?
514 What else did La Place discover?
515 What class of bodies are most *disturbed*? Why?
516 How much was the comet of 1682 retarded by Jupiter and Saturn?
517 Are planets in like manner disturbed by comets?
518 State the circumstances which prove this.

SECT. IV.

519 What is the cause of the spheroidal figure of the Earth and planets?
520 Illustrate this.
521 How much greater is the diameter of the Earth through the equator, than through the poles?
522 What striking fact results from this figure of the Earth?

SECT. V.

523 What is the precession of the equinoxes?
524 Explain the cause of it.

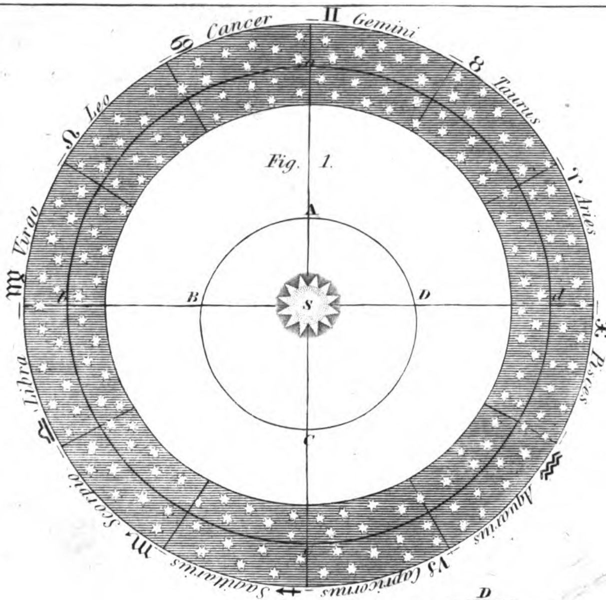
SECT. VI.

525 What are Tides?
526 What occasions them?
527 Illustrate.
528 In what region of the Earth are tides highest?
529 What effect does the Sun actually have on the tides?
530 What are Spring Tides?
531 What are Neap Tides?
532 In what time of the year are tides highest? Why?
533 What occasions inequality in the tides at places equally subject to the Moon's action?
534 At what places are tides very high?
535 How much higher are waters in the Red Sea than in the Mediterranean?
536 Why are the tides small in the Mediterranean and Baltic?
537 What is remarkable in the river Severn?
538 What in the river Thames?
539 What in the river Amazon?

THE END.

PLATE I.

Fig. 1.



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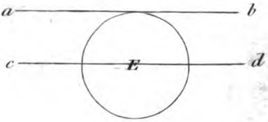

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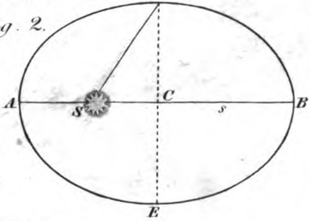

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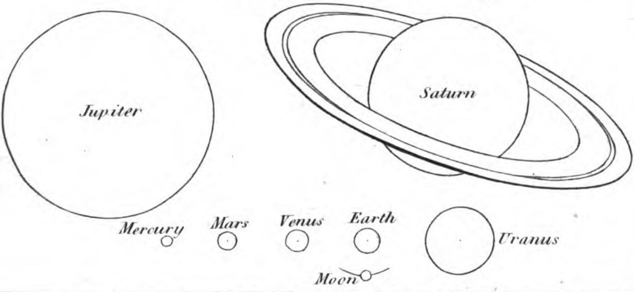

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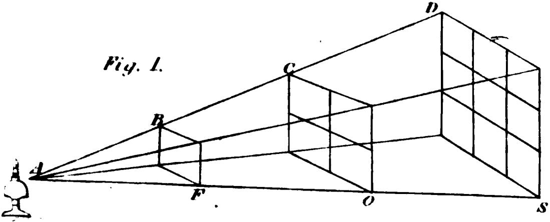

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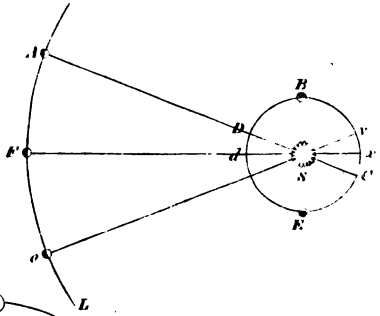

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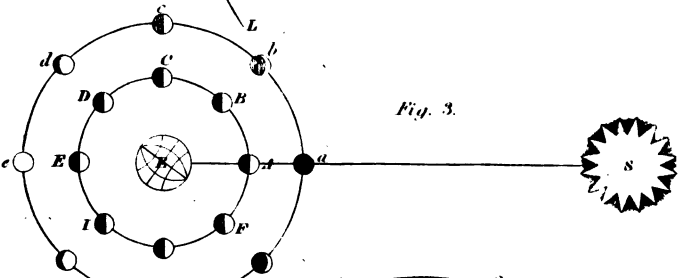

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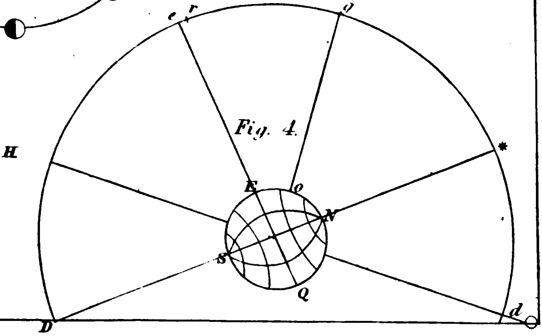

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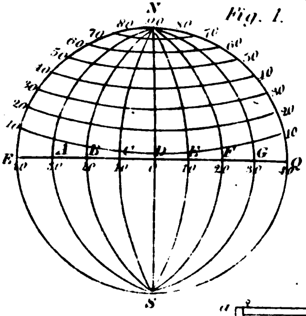

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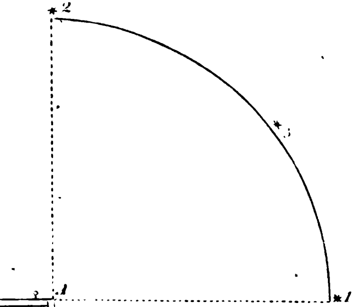

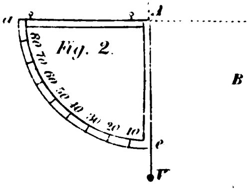

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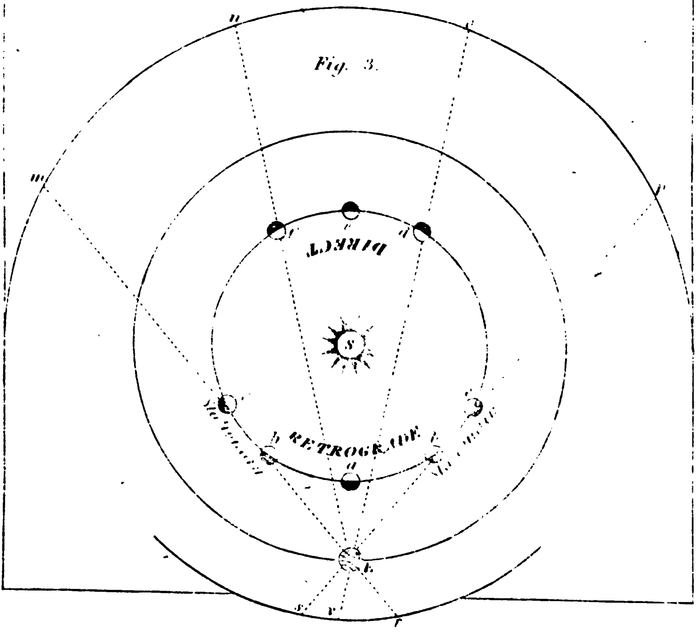
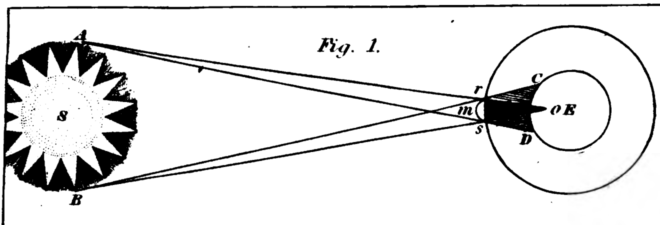


Fig. 3.

PLATE IV.

Fig. 1.



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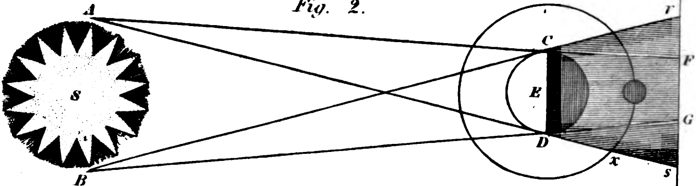

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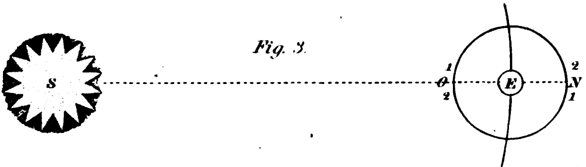

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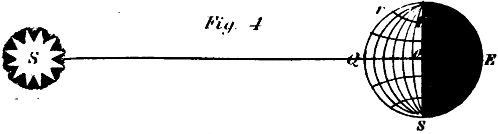

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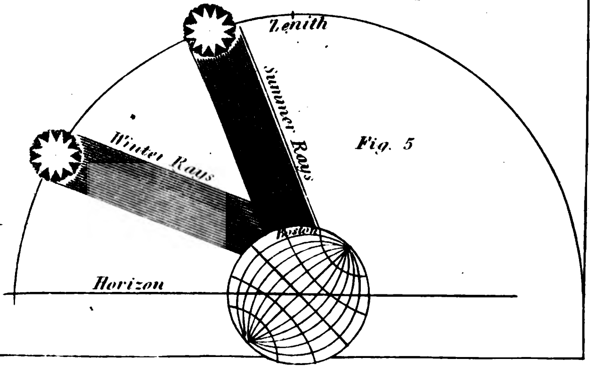

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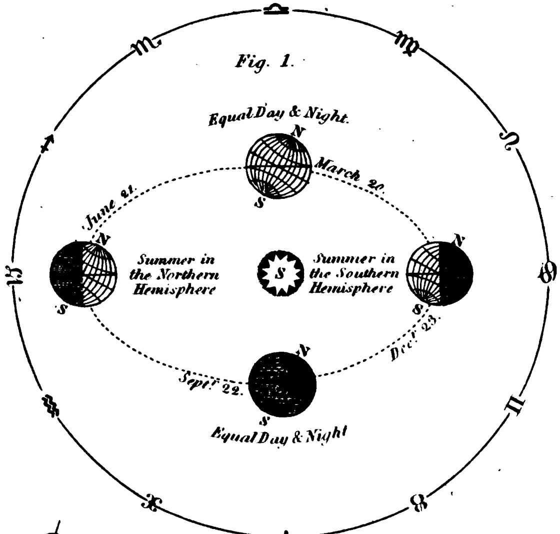

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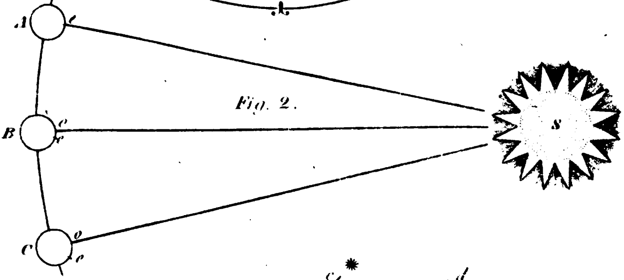

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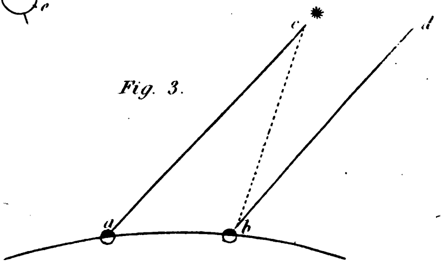

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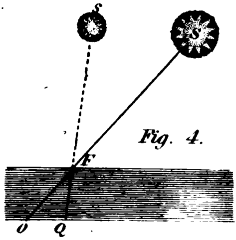
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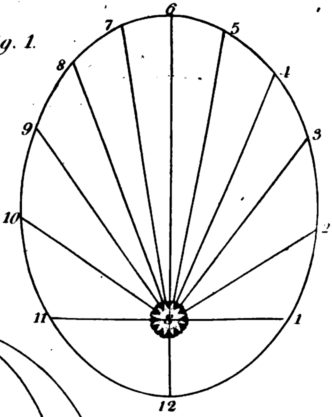
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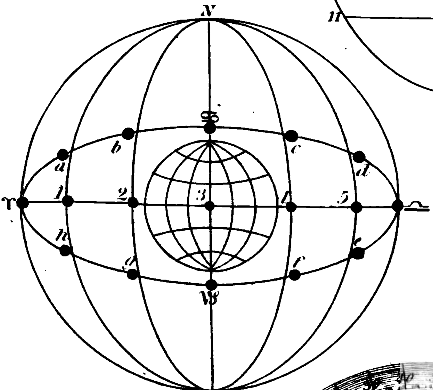

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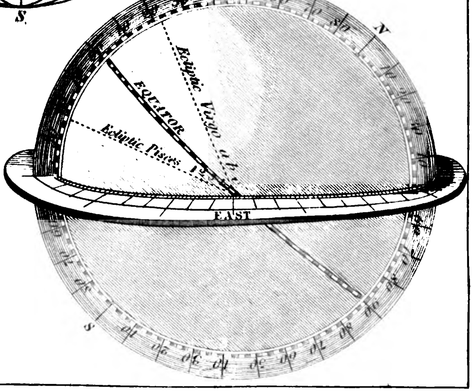

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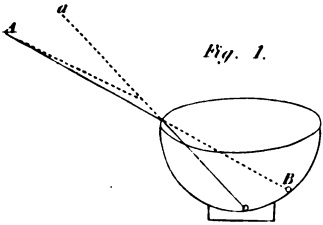

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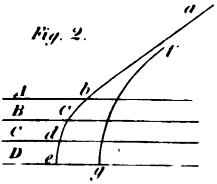

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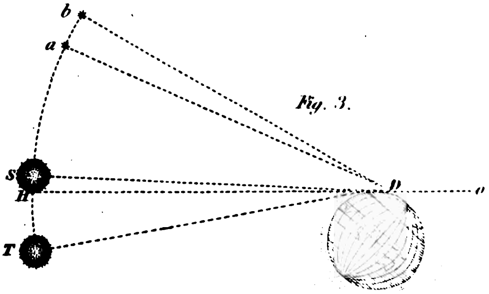

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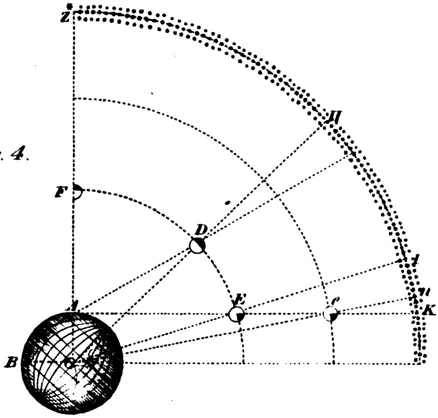

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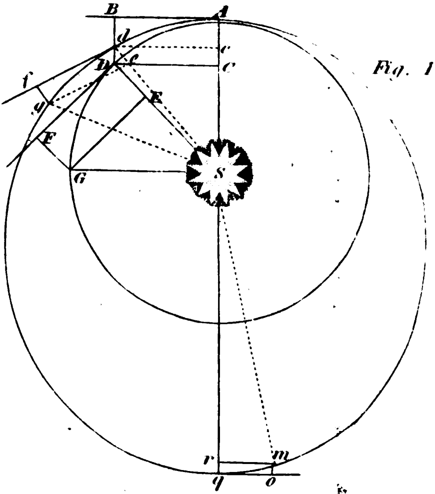

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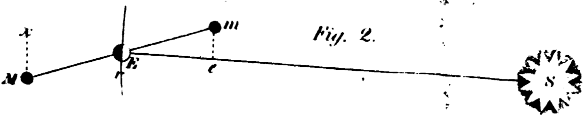

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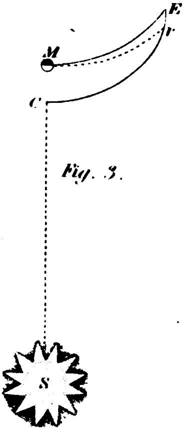

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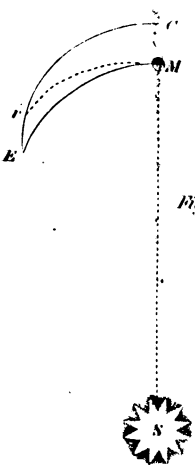

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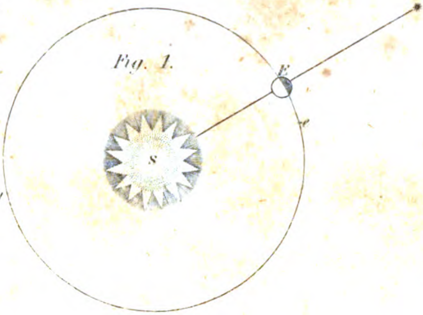

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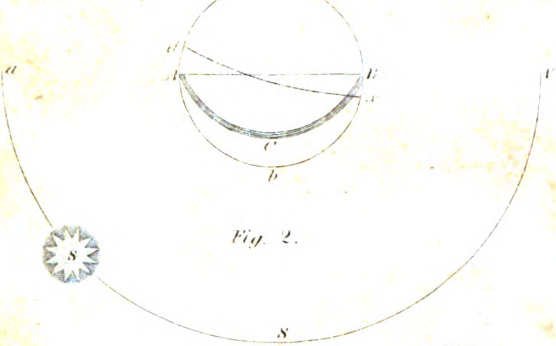

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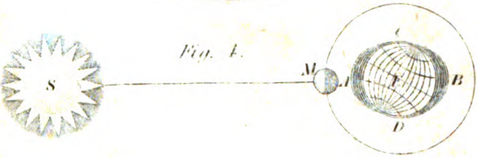

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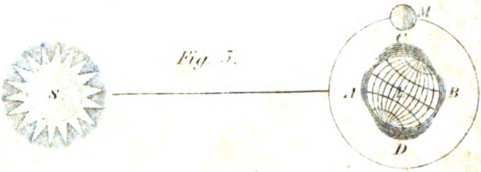

Fig. 5.